(12)

AFGL-TR-83-0187
ENVIRONMENTAL RESEARCH PAPERS, NO. 846

Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 6

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1 August 1983

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OPTICAL PHYSICS DIVISION PROJECT 7670
AIR FORCE GEOPHYSICS LABORATORY
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AIR FORCE SYSTEMS COMMAND, USAF

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-83-0187	2. GOVT ACCESSION NO. AD-A137 78[illegible]	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ATMOSPHERIC TRANSMITTANCE/RADIANCE: COMPUTER CODE LOWTRAN 6		5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim. 6. PERFORMING ORG. REPORT NUMBER ERP No. 846
7. AUTHOR(s) F.X. Kneizys J.H. Chetwynd, Jr. S.A. Clough E.P. Shettle L.W. Abreu R.W. Fenn W.O. Gallery J.E.A. Selby*		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (OPI) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F, 76700907 76701402
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (OPI) Hanscom AFB Massachusetts 01731		12. REPORT DATE 1 August 1983 13. NUMBER OF PAGES 200
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*Grumman Aerospace Corporation

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmospheric transmittance	Atmospheric optics	Solar/lunar
Atmospheric radiance	Radiative transfer	Scattering
Infrared	Attenuation	
Visible	Aerosols	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a computer code for predicting atmospheric transmittance and the thermal radiation emitted by the atmosphere and earth from 350 to 40,000 cm^{-1} at a spectral resolution of 20 cm^{-1}. The program is based on the LOWTRAN 5 (1980) computer code. Solar/lunar scattered radiation has been added to the code, as well as new spherical refractive geometry subroutines and an improved water vapor continuum model. Other modifications to the code include a wind-dependent maritime aerosol model, a vertical structure aerosol model, a cirrus cloud model, and a rain model.

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20. Abstract - Contd.

The computer code contains representative (geographical and seasonal) atmospheric models and representative aerosol models with an option to replace them with user-derived or measured values. The program can be run in one of three modes, namely, to compute only atmospheric transmittance, to compute atmospheric transmittance and radiance, or to compute atmospheric transmittance, atmospheric radiance, and scattered solar/lunar background radiance for a given slant path geometry.

Contents

Contents

Illustrations

Tables

Atmospheric Transmittance/Radiance: Computer Code Lowtran 6

1. INTRODUCTION

This report describes a Fortran computer code, LOWTRAN 6, designed to calculate atmospheric transmittance and radiance for a given atmospheric path at moderate spectral resolution. This code is an extension of the current LOWTRAN atmospheric code, LOWTRAN 5[1] (and its predecessors LOWTRAN 4,[2] LOWTRAN 3B,[3] LOWTRAN 3,[4] and LOWTRAN 2[5]). All the options and capabilities of the LOWTRAN 5 code have been retained. Solar/lunar scattered radiation

(Received for publication 29 July 1983)

1. Kneizys, F.X., Shettle, E.P., Gallery, W.O., Chetwynd, Jr., J.H., Abreu, L.W., Selby, J.E.A., Fenn, R.W., and McClatchey, R.A. (1980) Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 5, AFGL-TR-80-0067, AD A088215.
2. Selby, J.E.A., Kneizys, F.X., Chetwynd, Jr., J.H., and McClatchey, R.A. (1978) Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 4, AFGL-TR-78-0053, AD A058643.
3. Selby, J.E.A., Shettle, E.P., and McClatchey, R.A. (1976) Atmospheric Transmittance from 0.25 to 28.5 μm: Supplement LOWTRAN 3B, AFGL-TR-76-0258, AD A040701.
4. Selby, J.E.A., and McClatchey, R.A. (1975) Atmospheric Transmittance from 0.25 to 28.5 μm: Computer Code LOWTRAN 3, AFCRL-TR-75-0255, AD A017734.
5. Selby, J.E.A., and McClatchey, R.A. (1972) Atmospheric Transmittance from 0.25 to 28.5 μm: Computer Code LOWTRAN 2, AFCRL-TR-72-0745, AD A763721.

has been added to the code, as well as new spherical refractive geometry subroutines and an improved water vapor continuum model. Other new features of the code include a wind-dependent maritime aerosol model, a vertical structure aerosol model, a cirrus cloud model, and a rain model.

The LOWTRAN code calculates atmospheric transmittance and radiance, averaged over 20-cm^{-1} intervals in steps of 5 cm^{-1} from 350 to 40,000 cm^{-1} (0.25 to 28.5 μm). The code uses a single-parameter band model for molecular absorption, and includes the effects of continuum absorption, molecular scattering, and aerosol extinction. Refraction and earth curvature are included in the calculation of an atmospheric slant path. The code contains representative atmospheric and aerosol models, and the option to replace them with user-derived or measured values.

In this report, the new spherical refractive geometry subroutine is described in Section 2. The improved water vapor continuum model is presented in Section 3. Following this is a discussion of the calculation of single-scattered solar or lunar radiation in Section 4. In Sections 5 through 8, the wind-dependent maritime model, the vertical structure algorithm for boundary layer aerosols, a cirrus cloud model, and a rain model are presented. The structure of the new computer code is given in Section 9.

User instructions for the LOWTRAN code are given in Section 10 and examples of the output of the program in Section 11. A plotting program and a filter program are now included with the LOWTRAN code, and are explained in Appendices A and B. Appendix C defines the single scattering geometry while Appendix D explains the development of the standard LOWTRAN phase functions. The program listing along with the plot program and filter program listing are available in a supplement to the LOWTRAN 6 report.

In addition to the modeling work of the Air Force Geophysics Laboratory, special acknowledgement should be given to the contributions made by Sonicraft Incorporated, the Naval Research Laboratory, the Army Atmospheric Sciences Laboratory, and the National Oceanic and Atmospheric Administration to the LOWTRAN 6 model and code presented in this report.

The LOWTRAN 6 code will be made available from the National Climatic Center, Federal Building, Asheville, NC 28801 (see Section 9 for complete details on availability). It is requested that users receiving the code, send their name, affiliation, and address to us to update the AFGL LOWTRAN mailing list and for notification to users of changes in the code. Correspondence should be mailed to F.X. Kneizys, AFGL/OPI, Hanscom AFB, MA 01731.

2. AIR MASS COMPUTATION (SPHERICAL REFRACTIVE GEOMETRY)

2.1 Introduction

The transmittance and radiance along a path through the atmosphere depend upon the total amount and the distribution of the absorbing or scattering species along the path. The integrated amount along a path is known by various names, including "column density", "equivalent absorber amount", and "air mass". While the term "air mass" applies specifically to the total amount of gas along the path, it will be used here to refer loosely to the integrated amounts for all the different species relative to the amount for a vertical path. The calculation of air mass for realistic atmospheric paths requires that the earth's curvature and refraction be taken into account.

The model for calculating air mass has been greatly improved in LOWTRAN 6. The previous model assumed that the index of refraction was constant between layer boundaries. The new model assumes a continuous profile for the refractive index, with an exponential profile between layer boundaries. It is more accurate than the previous model and works for all paths. All the options from the previous model for specifying the slant paths have been retained.

This section describes the new model for calculating air mass and presents calculations of air mass for several representative atmospheric paths. For a more complete description of the method used here, see Reference 6.

2.2 Defining Equations

The atmosphere is modeled as a set of spherically symmetric shells with boundaries at the altitudes z_j, j = 1, N. The temperature, pressure, and absorber (gas and aerosol) densities are specified at the layer boundaries. Between boundaries, the temperature profile is assumed linear while the pressure and densities are assumed to follow exponential profiles. For example, the density ρ at an altitude z between z_j and z_{j+1} is given by

$$\rho(z) = \rho_j \exp\left[-(z-z_j)/H_\rho\right] \quad ,$$

where the density scale height H_ρ is

$$H_\rho = (z_{j+1} - z_j)/\ln(\rho_j/\rho_{j+1}) \quad .$$

The scale height varies with the layer and is different for pressure and density.

6. Gallery, W.O., Kneizys, F.X., and Clough, S.A. (1983) Air Mass Computer Program for Atmospheric Transmittance Radiance/Calculations: FSCATM, AFGL-TR-83-0065.

Consider an optical path through the atmosphere from point a to b as shown in Figure 1. The path is defined by the initial and final altitudes z_a and z_b and by the zenith angle θ_o at a. The other path quantities are: s, the curved path length from a; β, the earth-centered angle; ϕ, the zenith angle at b; and ψ, the total refractive bending along the path.

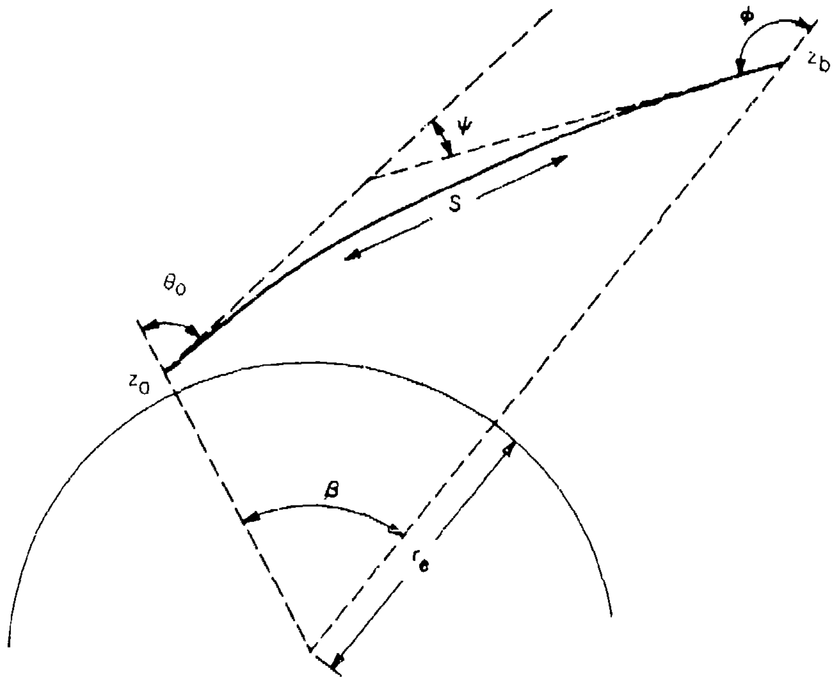


Figure 1. Slant Path Through the Atmosphere From Point a to Point b

The integrated amount u of an absorber of density $\rho(z)$ is given by:

$$u = \int_a^b \rho(z)\, ds \tag{1}$$

$$u = \int_a^b \rho(z)\, (ds/dz)\, dz \quad . \tag{2}$$

At any point along the path

$$ds/dz = (\cos\theta)^{-1} \quad , \tag{3}$$

where θ is the local zenith angle.

Due to the curvature of the earth and to refraction, θ varies along the path. However, if the zenith angle is less than about 80°, the variation of θ along the path is negligible and Eq. (2) can be written as

$$u = (\cos\theta_o)^{-1} \int_a^b \rho \, dz \quad . \tag{4}$$

Eq. (4) is called the secant approximation and is equivalent to assuming a plane-parallel atmosphere. The integral in Eq. (4) has a particularly simple form for an exponential density distribution:

$$\int_a^b \rho \, dz = H_\rho \left[\rho(z_a) - \rho(z_b)\right] \quad , \tag{5}$$

where H_ρ is the density scale height. If the path extends over several layers, each with a different scale height, then the integral in Eq. (5) must be broken into separate parts, one for each layer.

For the general case, curvature and refraction must be taken into account in Eq. (2). This is accomplished by a detailed numerical integration of Eq. (2) as follows. The interval from z_a to z_b is divided into a number of sub-intervals defined by $z_1, z_2, \ldots z_N$. The integral in Eq. (2) is approximated by the sum:

$$u = \sum_{i=1}^{N-1} \bar{\rho}_i \, \Delta s_i \quad , \tag{6}$$

where

$$\bar{\rho}_i = \frac{1}{\Delta z_i} \int_{z_i}^{z_{i+1}} \rho(z) \, dz \tag{7}$$

$$\Delta s_i = \int_{z_i}^{z_{i+1}} (ds/dz)\, dz \quad . \tag{8}$$

Since the density is assumed to follow an exponential profile, the integral in Eq. (7) can be written analytically as

$$\bar{\rho}_i = \frac{H_\rho}{\Delta z_i} [\rho(z_i) - \rho(z_{i+1})] \quad , \tag{9}$$

where the scale height H_ρ is constant over the layer from z_a to z_b. The integral in Eq. (8) can be obtained numerically as shown in the next section.

The number and spacing of the intervals z_i are chosen so that Eq. (6) is a good approximation to Eq. (2) as will also be shown. Again, if the path extends over several layers, with different scale heights in each, then the path integral must be performed separately for each layer. In the discussion that follows, it will be assumed that the path is confined to a single layer in which the scale heights are constant with altitude.

2.3 Atmospheric Refraction

The governing equation for a ray passing through the atmosphere is Snell's Law for a spherically symmetric medium, given by:

$$n(r)\, r \sin\theta = C \quad , \tag{10}$$

where n is the index of refraction, r is the radius to a point along the ray, θ is the zenith angle at that point, and C is a constant of the particular path. If the ray is horizontal at a point r_T, θ is = 90° at that point, and $C = n(r_T)r_T$; the altitude at that point is called the tangent height.

The index of refraction n is conveniently written as:

$$n(r) = 1 + N(r) \quad , \tag{11}$$

where N(r) is called the refractivity.* N is wavenumber dependent and, in the visible and the infrared, N is also very nearly proportional to the total air density. At sea level, in the infrared, N is of the order of 3×10^{-4}. In these

*See Section 2.6 for a discussion of the index of refraction.

calculations, we assume the N follows an exponential profile with a scale height H_N. H_N is determined separately for each atmospheric layer.

The effect of refraction is to bend the path in the direction of increasing N. The radius of curvature K of the refracted ray can be shown to be

$$K = -(n'/n) \sin \theta \quad , \tag{12}$$

where $n' = dn/dr$. It is useful to define the quantity R(r) as

$$R(r) = -\frac{r}{n/n'} \quad . \tag{13}$$

R is simply the ratio of r to the radius of curvature of a ray tangent at r. R is a property of the atmospheric profile and not the particular path and is a good measure of the importance of refraction at a particular altitude. For example, for the U.S. Standard Atmosphere, R is approximately 0.16 at sea level and decreases exponentially with altitude with a scale height of about 10 km.

To trace a ray through the atmosphere, consider the path shown in Figure 1: θ_o is the zenith angle at z_a, ϕ is the zenith angle at z_b, β is the earth-centered angle, and ψ is the bending along the path. Let s be the length of the path from point a. At any point the differential path quantities are given by:

$$ds = \frac{1}{\cos \theta} dr \tag{14}$$

$$d\beta = \tan \theta \frac{1}{r} dr \quad , \tag{15}$$

where θ is the zenith angle at the point. Substituting for $\cos \theta$ from Eq. (10) into Eq. (14) gives

$$ds = \left(1 - \frac{C^2}{n^2 r^2}\right)^{-1/2} dr \quad . \tag{16}$$

Eq. (16) is the basic atmospheric ray trace equation. If the function n(r) is known, then Eq. (16) can be integrated numerically along the path.

However, the difficulty with integrating Eq. (16) is that it has a singularity at $\theta = 90^o$, that is, at the tangent height, where $C = n(r_T)r_T$. A simple change of variables will remove this singularity and also provide some insight into the importance of refraction. Define a new independent variable x as:

$$x = r \cos\theta \quad , \tag{17}$$

(x can be interpreted as the straight line distance to the geometric tangent point). Differentiating Eq. (17) gives:

$$dx = [\cos\theta - r \sin\theta\,(d\theta/dr)]\; dr \quad . \tag{18}$$

Differentiating Eq. (10) and using Eq. (13) gives

$$d\theta/dr = -(1 - R) \tan\theta/r \quad . \tag{19}$$

Substituting Eq. (19) into Eq. (18) gives

$$dx = (1 - R \sin^2\theta)\; dr/\cos\theta \quad . \tag{20}$$

Comparing Eq. (20) with Eq. (14) gives

$$ds = (1 - R \sin^2\theta)^{-1}\; dx \quad . \tag{21}$$

In this form of the equation for ds, the right-hand side is a well-behaved function of r for all paths, including vertical and horizontal paths (except in the unusual case where $R \geq 1$ and the path curves back toward the earth, that is, looming). The intermediate variable $x = r \cos\theta$ is also well defined for all paths. In practice, the numerical integration of Eq. (21) is driven in steps of r, from r to $r + \Delta r$. The corresponding increment in x is calculated from Eq. (17). The integration of s from Eq. (21) is then straightforward.

2.4 Numerical Algorithm

The numerical algorithm used to evaluate Eq. (6) is as follows:

1. Find the minimum and maximum altitude HMIN and HMAX along the path and the zenith angle θ at HMIN. If the path goes through a tangent point, then solve Eq. (10) iteratively for the tangent height.

2. From the given atmospheric profile, construct a new profile at the layer boundaries from HMIN to HMAX, interpolating the pressure, temperature, and densities where necessary.

3. Starting with the lowest layer, trace the path through each layer:

a. Divide the layer into sublayers defined by the altitudes z_j such that $\Delta z_j = \widetilde{\Delta}s \cos\theta_{j-1}$, where $\widetilde{\Delta}s$ is a nominal path length (5 km) and θ_{j-1} is the zenith angle at z_{j-1}.

$$\Delta z_j = \tilde{\Delta} s \cos \theta_{j-1}$$

$$z_j = z_{j-1} + \Delta z_j$$

$r_j = r_e + z_j$ (r_e is radius of the earth)

$$n_j = 1 + N(z_j)$$

$$\sin \theta_j = \frac{C}{n_j r_j}$$

$$\cos \theta_j = (1 - \sin^2 \theta_j)^{1/2}$$

$$x_j = r_j \cos \theta_j$$

$$\Delta x_j = x_j - x_{j-1}$$

$$R_j = -r_j/[(dN/dr|_j)/n_j]$$

$$ds/dx|_j = (1 - R_j \sin^2 \theta_j)^{-1}$$

$$\Delta s_j = 1/2 \; (ds/dx|_{j-1} + ds/dx|_j) \; \Delta x_j \quad .$$

b. For each species, integrate the density ρ:

$$\rho_j = \rho(z_j)$$

$$\bar{\rho}_j = H_\rho \; (\rho_j - \rho_{j+1})/\Delta z_j$$

$$u = \sum_{j=1}^{N-1} \bar{\rho}_j \; \Delta s_j \quad .$$

2.5 Examples of Air Mass Calculation

This section will present plots of air mass values for three classes of slant paths. The term "air mass values" refers to the integrated amount of air along a path compared to the amount for a vertical path from ground to space. For example, the air mass value for a path from the ground to space with the zenith angle at the ground of 90° is 38.1 for the U.S. Standard Atmosphere (one air mass equals 2.15×10^{25} molecules cm^{-2} or 1.034×10^{3} gm cm^{-2}). These three paths are described by the initial altitude "H1" and the zenith angle "ANGLE" at H1. The other end of the path is the top of the atmosphere, here taken to be 100 km. The three classes of paths are: 1) H1 = 0 km for ANGLE varying from 0 to 90°; 2) ANGLE = 90° for H1 varying from 0 to 50 km; 3) H1 = 30 km for ANGLE varying from 85° to 95.1° at which point the path intersects the earth. The wavenumber for these calculations was 2000 cm^{-1} (5 μm). The dependence of air mass on wavenumber in the infrared is small.

In addition to the air mass value, the amounts of water vapor and of ozone relative to the amounts for a vertical path from ground to space are also shown. The relative amounts of these gases depend upon their vertical distribution; in these cases, the 1962 U.S. Standard Atmosphere density profiles are used. Since the distributions of these gases in the atmosphere are so variable, the relative amounts for other profiles could be significantly different. The values for water vapor and ozone shown here should be taken to be illustrative only.

Figure 2 (a and b) shows the air mass value, relative water vapor, and ozone amounts for path 1. Also shown in Figure 2(b) is the secant of the zenith angle. For a large zenith angle, the relative amount of water vapor is greater than the air mass value while the amount of ozone is less. This effect is due to the fact that for large zenith angles, the greater part of the path is near the ground. Water vapor is concentrated in the lower layers so that the relative amount of water vapor is large compared to the vertical path. Ozone, however, is concentrated in the stratosphere, which contains a relatively small part of the path. Note that the secant agrees to better than one percent with the air mass value up to 72°, up to 80° for water vapor, but only up to 60° for ozone. The discrepancy is due mainly to the effect of the earth's curvature and not refraction; by including curvature but neglecting refraction, the relative amounts can be calculated to better than one percent up to 84° for air, 86° for water vapor, and 82° for ozone.

Figure 3 shows the air mass values and relative amounts for path 2. These curves mimic the density profiles of air, water vapor, and ozone themselves since the bulk of the gas is located within a few kilometers (vertically) of the observer altitude.

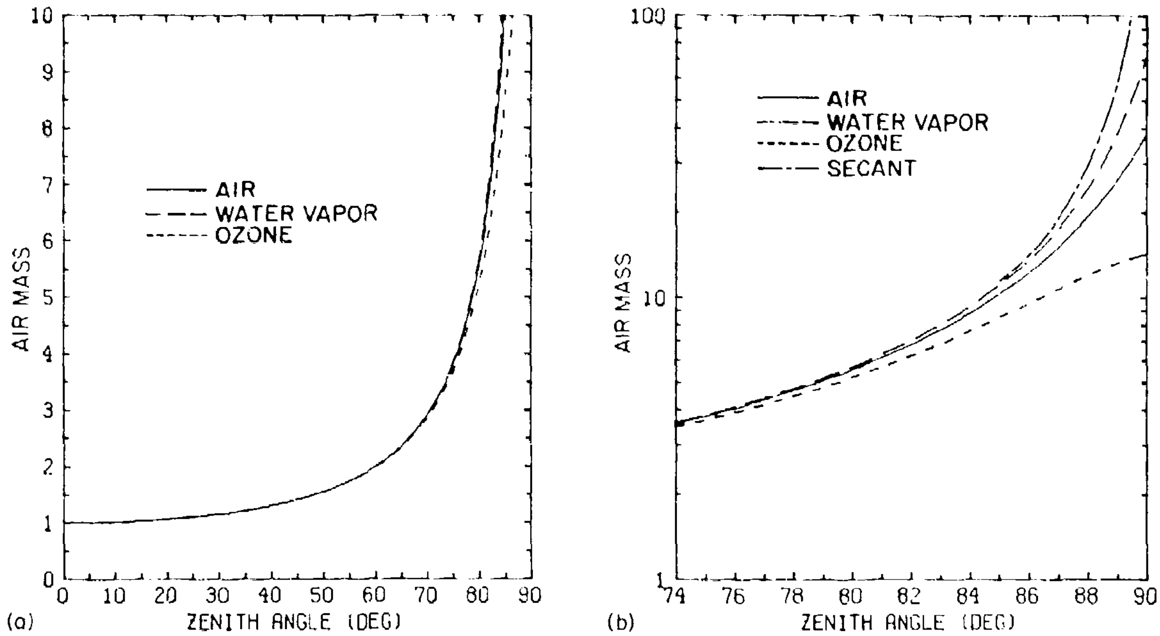


Figure 2. Relative Absorber Amounts vs Zenith Angle for Path 1. (a) 0 to 90° and (b) 74 to 90° (also shown is the secant of the zenith angle)

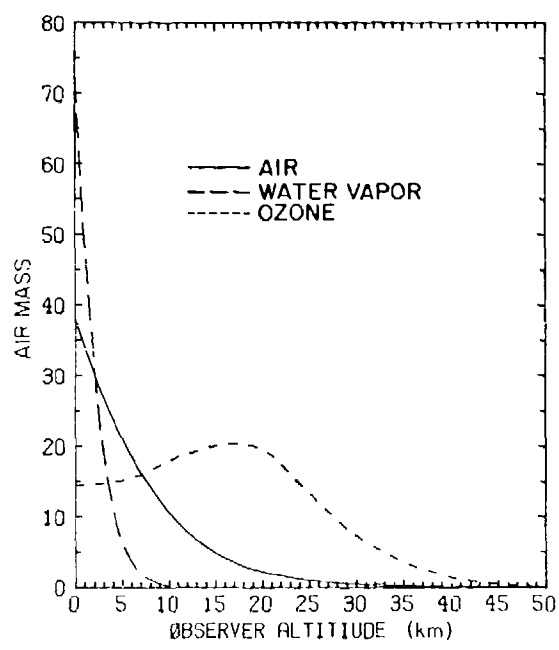


Figure 3. Relative Absorber Amounts vs Observer Altitude (H1) for Path 2

The relative amounts shown in Figure 4 correspond to path 3, which is typical of a stratospheric balloon-borne experiment looking at the sun as it sets. Also shown on the right-hand axis is the tangent height vs zenith angle and the angular diameter of the sun. If the sun is used as the source for a measurement, the air mass value to different points on the face of the sun can vary by a factor of 2 for large zenith angles. The variation in air mass due to this effect can be a major source of uncertainty in the measurement and must be considered carefully.

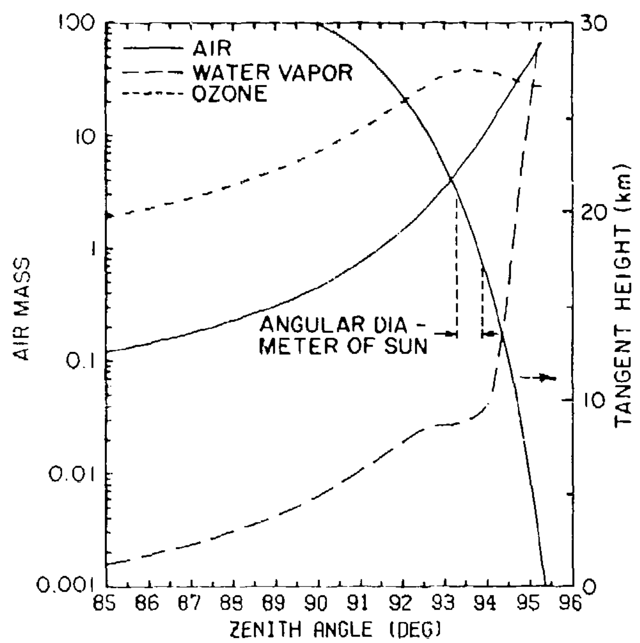


Figure 4. Relative Absorber Amounts vs Zenith Angle for Path 3. Also shown against the right-hand axis is the tangent height vs zenith angle and the angular diameter of the sun

Two other quantities of interest for atmospheric profiles are the tangent height and the refractive bending. The difference in tangent height between an unrefracted and a refracted ray coming in from space is shown as a function of the refracted tangent height in Figure 5 for three atmospheric profiles (the geometry is shown schematically in the inset). The total refractive bending for paths 1 and 2 are shown in Figures 6 and 7 for three atmospheric profiles. Note that the total bending for a path from the ground to space at 90° for the

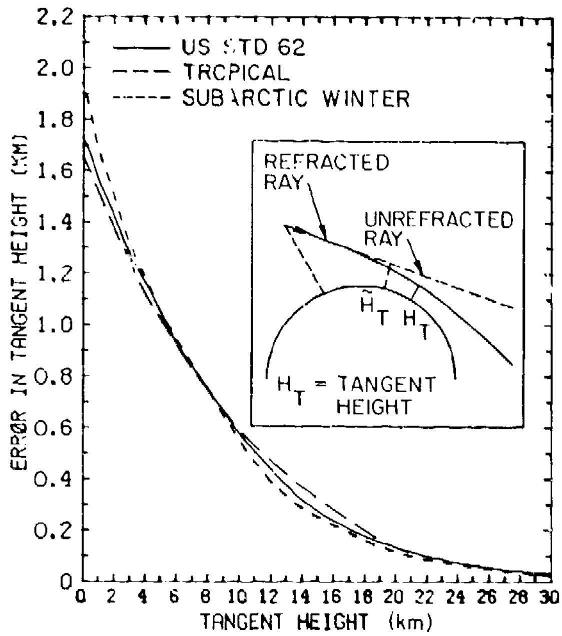
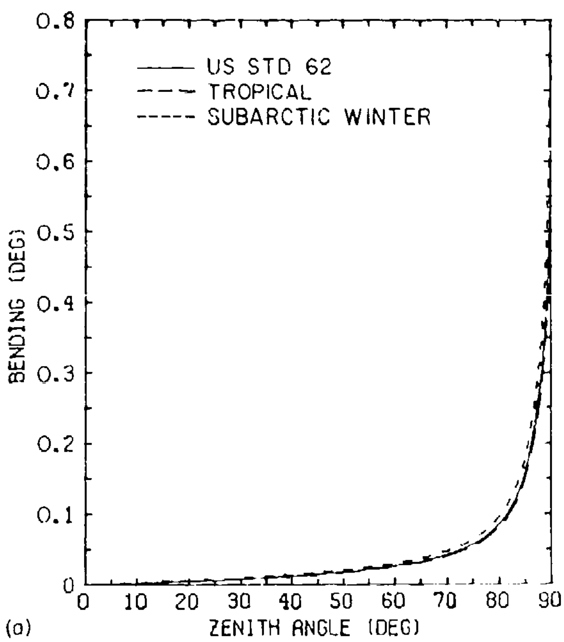


Figure 5. Unrefracted Tangent Height Minus Refracted Tangent Height vs Refracted Tangent Height for a Ray Coming in From Space for Three Atmospheric Profiles. The figure in the inset illustrates the paths



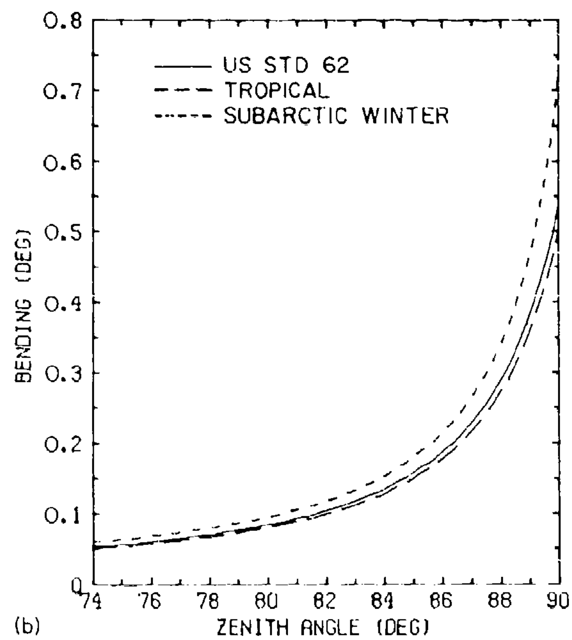


Figure 6. Refractive Bending vs Zenith Angle for Path 1, for Three Atmospheric Profiles. (a) 0 to 90° and (b) 74 to 90°

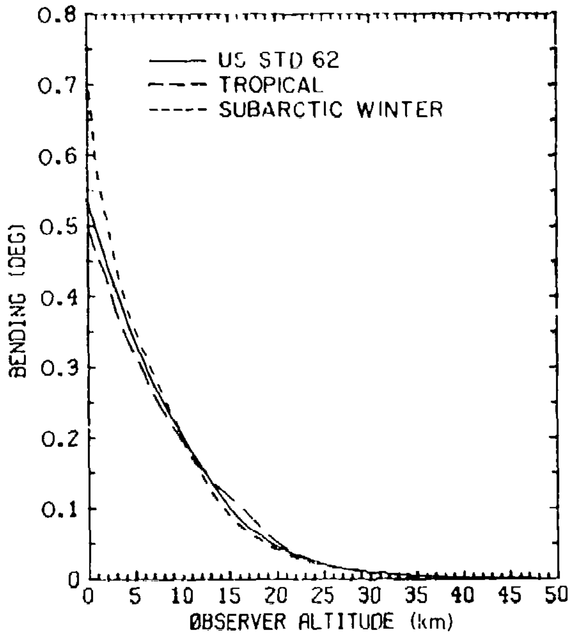


Figure 7. Refractive Bending vs Observer Altitude (H1) for Path 2, for Three Atmospheric Profiles

U.S. Standard Atmosphere and the Tropical Atmosphere is about 0.5°, which is the same as the solar diameter.

2.6 Index of Refraction

The equation for the index of refraction n is taken from Edlen[7] and is given by:

$$(n - 1) \times 10^6 = \left[a_o + \frac{a_1}{1 - (\nu/b_1)^2} + \frac{a_2}{1 - (\nu/b_2)^2} \right] \cdot \frac{(P - P_w)}{P_o} \cdot \frac{296.15}{T}$$

$$+ \left[c_o - (\nu/c_1)^2 \right] \frac{P_w}{P_o} \quad ,$$

where ν is the wavenumber in cm^{-1}, P is the total pressure in mb, P_w is the partial pressure of water vapor, P_o is 1013.25 mb, T is the temperature in Kelvin, and the constants a, b, and c are

7. Edlen, K. (1966) The refractive index of air, Metrologia 2:12.

$a_o = 83.43,\ a_1 = 185.08,\ a_2 = 4.11$

$b_1 = 1.140 \times 10^5,\ b_2 = 6.24 \times 10^4$

$c_o = 43.49,\ c_1 = 1.70 \times 10^4$.

The formula used in previous versions of LOWTRAN was a simplified version of this expression.

3. WATER VAPOR CONTINUUM

A new water vapor continuum model has been added to LOWTRAN 6. This model for the continuum contribution from water vapor absorption was originally developed by Clough et al[8] for use with the line-by-line transmittance and radiance atmospheric code, FASCODE.[9]

For atmospheric applications it is advantageous to express the density dependence of the water vapor continuum absorption in terms of a self and foreign component. The continuum contribution to the absorption coefficient $k_C(\nu)$, is given by the expression

$$k_C(\nu) = \rho_s \nu \tanh(hc\nu/2kT) \left[\left(\frac{\rho_s}{\rho_o}\right) \tilde{C}_s(\nu, T) + \left(\frac{\rho_f}{\rho_o}\right) \tilde{C}_f(\nu, T) \right] \tag{22}$$

where T is the temperature (^oK), ν the wavenumber (cm^{-1}), $hc/k = 1.43879$ $^oK/cm^{-1}$ (ρ_s/ρ_o) and (ρ_f/ρ_o) are the number density ratios for the self and foreign continuum; and $\tilde{C}_s$ and $\tilde{C}_f$ $[(cm^{-1}\ mol/cm^2)^{-1}]$ are wavenumber dependent continuum absorption parameters for the self and foreign components. The density ρ_s is the density of the water vapor and ρ_f is the density of all other molecular species; consequently, $\rho_s + \rho_f$ represents the total density. The quantity, ρ_o, is the reference number density defined at 1013 mb and 296K. The present formulation in terms of density has the advantage that the continuum contribution to the absorption coefficient decreases with increasing temperature through the number

8. Clough, S.A., Kneizys, F.X., Davies, R., Gamache, R., and Tipping, R.H. (1980) Theoretical line shape for H_2O vapor; Application to the continuum, Atmospheric Water Vapor, A. Deepak, T.D. Wilkerson, and L.H. Ruhnke, Eds., Academic Press, New York.

9. Clough, S.A., Kneizys, F.X., Rothman, L.S., and Gallery, W.O. (1981) Atmospheric spectral transmittance and radiance: FASCODE 1B, Proceedings of SPIE, The Inter. Soc. for Opt. Eng., 277, Atmospheric Transmission, R.W. Fenn, Ed., April 1981.

density ratio term. The quantities $\widetilde{C}_s$ and $\widetilde{C}_f$ for water vapor are stored in the program for the spectral range 0 to 20,000 cm^{-1}.

The values for $\widetilde{C}_s$ for water vapor at 296K are shown in Figure 8 together with the experimental values obtained by Burch et al.[10-13] The strong temperature dependence of the self density dependent water vapor continuum is treated by storing values of C_s at 260K and 296K and linearly interpolating between the 260K and 296K values. The 260K result was obtained by extrapolating the fits to the 338K and 296K data of Burch et al.[12] The results for 260K and 296K are shown in Figure 9.

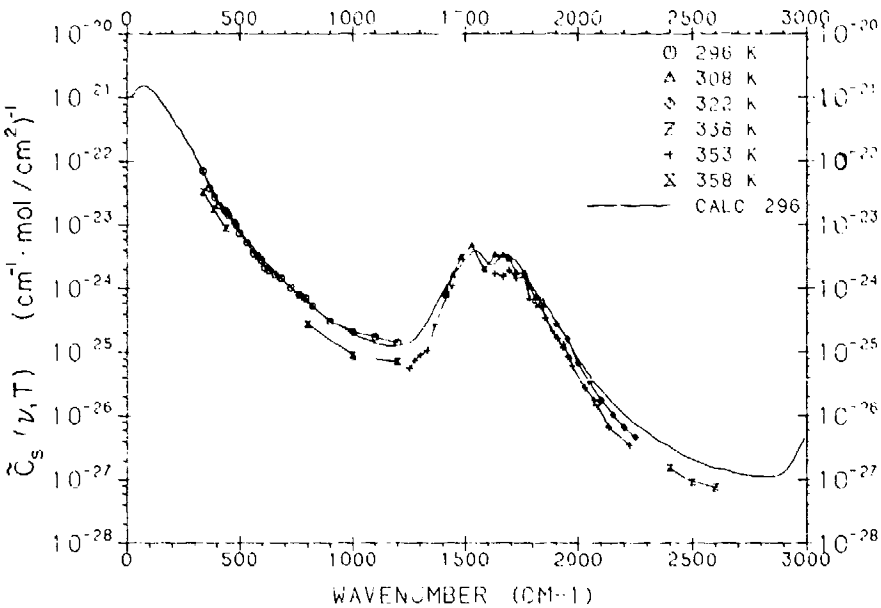


Figure 8. The Self Density Dependent Continuum Values, $\widetilde{C}_s$, for Water Vapor as a Function of Wavenumber. The experimental values are from Burch, et al

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10. Burch, D.E., and Gryvnak, D.A. (1979) Method of Calculating H_2O Transmission Between 333 and 633 cm^{-1}, AFGL-TR-79-0054, AD A072850; Aeronutronic Report No. U-6503, April 1979.

11. Burch, D.E., and Gryvnak, D.A. (1978) Infrared Absorption by CO_2 and H_2O, AFGL-TR-78-0154, AD A060079; Aeronutronic Report No. U-6417, May 1978.

12. Burch, D.E., Gryvnak, D.A., and Pembroke, J.D. (1971) Investigation of Absorption by Atmospheric Gases, AFCRL-71-0124, AD A882876; Aeronutronic Report No. U-4897, January 1971.

13. Burch, D.E. (January 1970) Semi-Annual Technical Report, Aeronutronic Report No. U-4784.

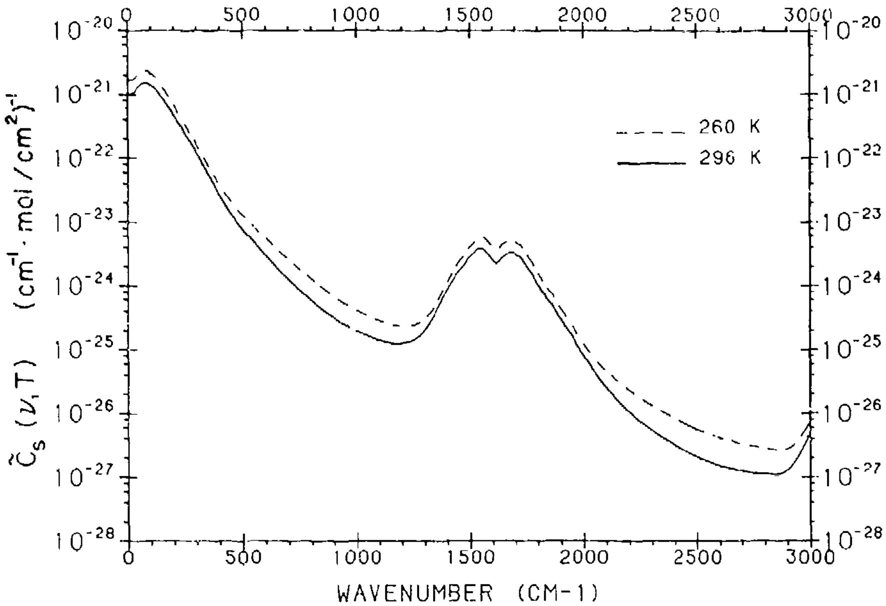

Figure 9. The Self Density Dependent Continuum Values, $\tilde{C}_s$, for Water Vapor as a Function of Wavenumber at 260K and 296K. The values from 296K are fits to experimental results; the 260K result is extrapolated

Only values near room temperature are available for the foreign dependence of the water vapor continuum. The continuum values $\tilde{C}_f$ at 296K are shown in Figure 10 and have been obtained by a fit to the data of Burch. There is still considerable uncertainty in the foreign values for the spectral window regions at 1000 and 2500 cm^{-1}.

In the LOWTRAN code, the total optical depth due to water vapor continuum absorption for an atmospheric slant path of N layers is given by

$$\sum_{i=1}^{N} \int_i k_c(\nu)ds = C_s(\nu,296) \sum_{i=1}^{N} \int_i \left(\frac{\rho_s}{\rho_o}\right) \rho_s \, ds \; +$$

$$[C_s(\nu,260) - C_s(\nu,296)] \sum_{i=1}^{N} \left(\frac{296-T_i}{296-260}\right) \int_i \left(\frac{\rho_s}{\rho_o}\right) \rho_s \, ds \; + \qquad (23)$$

$$C_f(\nu,296) \sum_{i=1}^{N} \int_i \left(\frac{\rho_f}{\rho_o}\right) \rho_s \, ds \quad ,$$

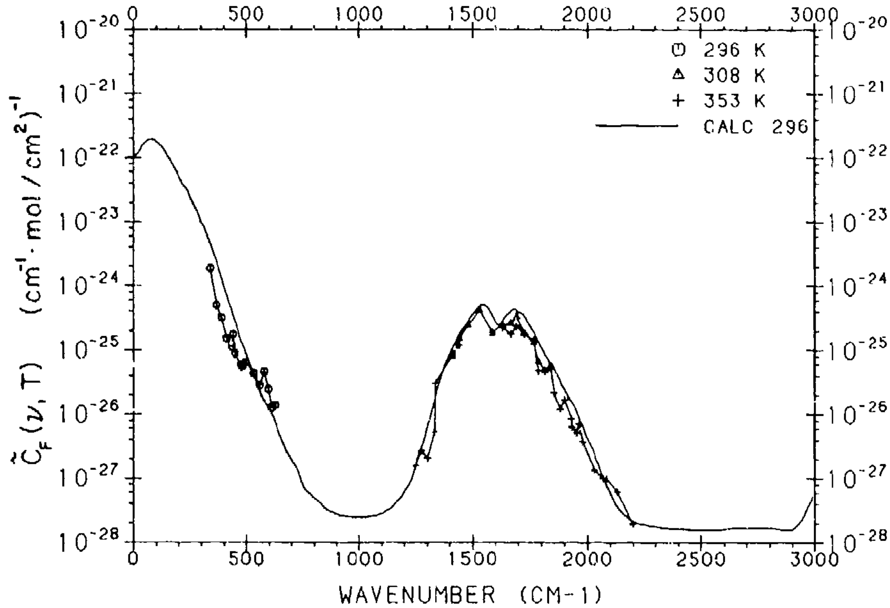

Figure 10. The Foreign Density Dependent Continuum Values, C_f, for Water Vapor as a Function of Wavenumber. The experimental values are from Burch, et al

where ds is the incremental path length, T_i is the temperature of the i'th layer, and

$$C_s(\nu, 296) = \nu \tanh(hc\nu/2k(296))\ \tilde{C}_s(\nu, 296)$$

$$C_s(\nu, 260) = \nu \tanh(hc\nu/2k(260))\ \tilde{C}_s(\nu, 260) \tag{24}$$

$$C_f(\nu, 296) = \nu \tanh(hc\nu/2k(296))\ \tilde{C}_f(\nu, 296)$$

Calculations of atmospheric slant path transmittance using the new water vapor continuum absorption coefficients will result in approximately the same attenuation as in the LOWTRAN 5 model for the atmospheric window regions from 8 to 12 μm and 3.5 to 4.2 μm. However, for other spectral regions, particularly from 4.5 to 5.0 μm, significant improvement in atmospheric transmittance calculations has been made with the inclusion of the contribution of continuum absorption.

4. SOLAR/LUNAR SINGLE SCATTERING MODEL

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4.1 Introduction

The radiation propagating through the atmosphere originates from the following sources: gaseous emission along the line-of-sight, transmitted extraterrestrial (solar/lunar) sources or background emission (earth or target), and radiation scattered into the line-of-sight by aerosols or molecules.

Previous versions of LOWTRAN have calculated atmospheric radiance due only to gaseous and background emissions. While in many cases these two sources dominate the atmospheric radiance, there are other cases of interest where the scattered radiance is of equal or greater importance. Until now LOWTRAN has treated scattering only as a loss mechanism.

A number of techniques exist that include the full effects of scattering on atmospheric radiance: these include for example, Monte Carlo and "adding/doubling" techniques. These techniques take into account multiple scattering and can include both external and internal sources. These techniques however, tend to be computationally expensive and some of them are incompatible with the spectrally-averaged band model used in LOWTRAN.

In many situations, a complete multiple scattering calculation is not necessary and the scattered radiation is dominated by solar radiation that has been scattered only once. Calculation of the single solar (or lunar) scattered radiation is relatively simple and fits well within the context and structure of LOWTRAN.

Calculation of single scattering has been incorporated as an option in LOWTRAN 6. The next two sections of this chapter develop the algorithm for single scattering and show the verification of the LOWTRAN 6 calculations against other methods. Then the phase functions for scattering by atmospheric aerosols and molecules will be explained. Next, sample calculations of solar scattering are shown that illustrate the conditions where the singly scattered radiation becomes significant compared to the emitted radiation. Finally, recommendations are given concerning the range of applicability of the single scattering model. For a more detailed discussion of the single scattering model, see Reference 14.

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14. Ridgway, W.L., Moose, R.A., and Cogley, A.C. (1982) Single and Multiple Scattered Solar Radiation, AFGL-TR-82-0299, AD A126323.

4.2 Radiative Transfer

Before proceeding further, it will be helpful to introduce the following nomenclature:

SUPERSCRIPTS:

A	aerosol
M	molecular

SUBSCRIPTS:

e	extinction
a	absorption
s	scattering
ps	primary solar path (sun to scattering point)
op	line-of-sight optical path (scattering point to observer)

OTHER QUANTITIES:

k	monochromatic volumetric extinction, absorption, or scattering coefficient
$\tau = e^{-ks}$	monochromatic transmittance over a homogeneous path length s due to extinction absorption, or scattering
$P(\gamma)$	scattering phase function for a scattering angle γ
I^{SUN}	solar extraterrestrial intensity
I^{MOON}	lunar extraterrestrial intensity

Note that the dependence of most quantities on the spectral frequency ν will be shown by a subscript ν, although it will sometimes be suppressed for simplicity of notation when the concept is clear from context.

The monochromatic intensity (radiance) seen by an observer looking along a particular directional path is the sum of contributions from all sources lying along the line-of-sight. The sources are either primary sources (infrared emission) or scattering sources. The scattering source function J for scattering points along the observer's line-of-sight can be expressed in terms of the local incoming intensity at each point $I_\nu(\hat{n}')$ by

$$J_\nu(\hat{n}) = \int I_\nu(\hat{n}') \left(P_\nu^A k_s^A + P_\nu^M k_s^M \right) d\Omega' \quad , \tag{25}$$

where $\hat{n}$ is the unit vector directed toward the observer and $\hat{n}'$ (Ω') is to be integrated over the solid angle denoted by Ω'. With only single solar/lunar scattering included, the incident intensity $I_\nu(\hat{n}')$ is given by

$$I_\nu(\hat{n}') = I_\nu^{SUN} \, \tau_{e,ps}^{A+M} \, \delta(\hat{n}', \hat{n}_s') \quad , \tag{26}$$

where $\hat{n}_s'$ is the direction of the incident solar/lunar radiation at the scattering point. A schematic of the scattering geometry for a particular sun/observer orientation is displayed in Figure 11. The path that the sunlight/moonlight takes in passing through the atmosphere prior to being scattered at any scattering point P will be called the 'primary solar' path. Other sources besides direct extra-terrestrial illumination could of course contribute to the prescattered intensity $I_\nu(\hat{n}')$. One might include other direct sources such as gaseous emission and boundary surface radiation plus previously scattered radiation, but only unscattered sunlight/moonlight is included in the present scattering source function. The resulting source function is found by using Eq. (26) in Eq. (25) to obtain

$$J_\nu = I_\nu^{SUN} \tau_{e,ps}^{A+M} \left(P_\nu^A(\gamma) k_s^A + P_\nu^M(\gamma) k_s^M \right) \quad . \tag{27}$$

Note that P^A, P^M, k_s^A, and k_s^M vary with altitude (atmospheric density and composition) and are generally slowly varying functions of frequency. Note also that the scattering angle $\gamma = \arccos(\hat{n} \cdot \hat{n}_s')$ would be constant (independent of the particular scattering point) along a line-of-sight in the absence of refractive bending. Both the primary solar path and the line-of-sight optical path actually bend somewhat, so that γ can be expected to vary by as much as a few degrees along the line-of-sight. The primary solar transmittance $\tau_{e,ps}^{A+M}$ depends strongly on the optical path length of the primary solar path (prior to scattering), so that this factor can be expected to vary considerably from one scattering point to the next.

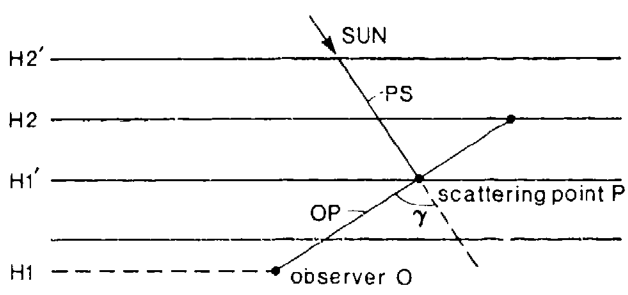

Figure 11. Schematic Representation of the Single Scattering Geometry. The scattering point at H1' is shown for an observer looking up from an altitude H1

The monochromatic intensity at the observer due to all of the single scattering sources within the line-of-sight is obtained by summing over the optical path the product of the source function and the transmission function that gives

$$I_\nu^{SCAT} = \int J_\nu \, \tau_{e,op}^{A+M} \, ds_{op}$$

$$= I_\nu^{SUN} \int \tau_{e,ps}^{A+M} \, \tau_{e,op}^{A+M} \left(P_\nu^A k_s^A + P_\nu^M k_s^M \right) ds_{op} \quad . \tag{28}$$

The scattering optical depth increment $k_s \, ds_{op}$ can be expressed in terms of the incremental transmittance for both aerosol and molecular scattering as

$$k_s^X \, ds_{op} = \frac{d\tau_{s,op}^X}{\tau_{s,op}^X} \quad , \tag{29}$$

with X being either A or M. The intensity can therefore be written as

$$I_\nu^{SCAT} = I_\nu^{SUN} \int \tau_{e,ps+op}^{A+M} \left[P_\nu^A \frac{d\tau_{s,op}^A}{\tau_{s,op}^A} + P_\nu^M \frac{d\tau_{s,op}^M}{\tau_{s,op}^M} \right] \quad , \tag{30}$$

which includes two separate integrals covering aerosol and molecular scattering effects. The above equation, which provides for a monochromatic calculation at any frequency ν, is now adapted for use with the molecular band transmission model used in LOWTRAN. The spectrally averaged intensity $\bar{I}$ is formally defined in terms of a convolution of the spectral intensity with a triangular instrument shape function $g(\nu)$ taken over a spectral width (half width at half maximum) of approximately $\delta\nu = 10 \text{ cm}^{-1}$, that is,

$$\bar{I}_\nu = \frac{1}{\delta\nu} \int I_\nu \, g(\nu - \nu') \, d\nu' \quad . \tag{31}$$

The spectrally averaged, scattered intensity can be expressed in terms of known LOWTRAN quantities provided that only the molecular absorption transmittance is a rapidly varying function of frequency. All other quantities are assumed to be constant over the spectral interval $\delta\nu$. The result is

$$\bar{I}_{\nu}^{SCAT} = \bar{I}_{\nu}^{SUN} \int \bar{\tau}^{A+M}_{e,ps+op} \left[P_{\nu}^{A} \frac{d\tau^{A}_{s,op}}{\tau^{A}_{s,op}} + P_{\nu}^{M} \frac{d\tau^{M}_{s,op}}{\tau^{M}_{s,op}} \right] . \tag{32}$$

The quantity $\bar{\tau}^{A+M}_{e,ps+op}$ represents the spectrally averaged transmittance that is calculated in LOWTRAN. Therefore, the molecular band models and aerosol models of LOWTRAN provide a direct means of calculating the path transmittance required for each of the scattering points. In order to maintain compatibility with the spherical shell atmosphere of LOWTRAN, the integral over the path of scattering sources is replaced by a layer-by-layer sum along the line-of-sight. For an optical path traversing N layers in an upward or downward direction this process gives

$$\bar{I}_{\nu}^{SCAT} = \bar{I}_{\nu}^{SUN} \sum_{j=1}^{N} \left[< \frac{\bar{\tau}^{A+M}_{e,ps+op} P^{A}_{j}}{\tau^{A}_{s,op}} >j \; \Delta\tau^{A}_{s,op,j} \right.$$

$$\left. + < \frac{\bar{\tau}^{A+M}_{e,ps+op} P^{M}_{j}}{\tau^{M}_{s,op}} >j \; \Delta\tau^{M}_{s,op,j} \right] . \tag{33}$$

The quantity $\Delta \tau_j$ is the change in molecular or aerosol scattering transmittance in passing through layer j, while $< >j$ denotes an average value for that layer.

Evaluating Eq. (33) requires the equivalent absorber amounts for both the line-of-sight and the primary solar paths associated with each scattering point plus the scattering angle at each scattering point. The calculation of these amounts and angles is described in Appendix C. The layer-by-layer sum of the singly scattered intensity is computed simultaneously with the existing direct thermal radiance using the following expression

$$\bar{I}_{\nu}^{SCAT} = \bar{I}_{\nu}^{SUN} \sum_{i=1}^{n-1} \sum_{X=(A,M)} \left[\tau^{X}_{s,op,i} - \tau^{X}_{s,op,i+1} \right] \times$$

$$1/2 \left[\frac{\bar{\tau}^{A+M}_{e,ps+op,i} P^{X}_{i}}{\tau^{X}_{s,op,i}} + \frac{\bar{\tau}^{A+M}_{e,ps+op,i+1} P^{X}_{i+1}}{\tau^{X}_{s,op,i+1}} \right] , \tag{34}$$

where n is the number of scattering points (layer boundaries). The layer average $< >j$ in Eq. (33) has been evaluated in Eq. (34) using the properties of only the

two scattering points that bound each layer path segment. In this scheme, the observer position coincides with i = 1 and the end of the line-of-sight with i = n.

If the optical path intersects the earth, then Eq. (34) has an additional term representing the sunlight reflected from the ground. The ground is assumed to be a diffuse Lambertian reflector. The irradiance at the ground is proportional to cos (θ), where θ is the solar zenith angle at the ground. The ground reflected sunlight is given by the term

$$\bar{I}_{\nu}^{SUN} \; \tau_{e,ps+op,n} \; A \cos(\theta)/2\pi \quad , \tag{35}$$

where A is the ground albedo.

The ground albedo is assumed to be independent of frequency and is read in as an input to LOWTRAN with a default of 0 (no reflection).

The extraterrestrial solar intensity $\bar{I}_{\nu}^{SUN}$ is obtained from the data compiled by Thekaekara.[15] The intensity is corrected for variation in the earth-to-sun distance due to the earth's elliptical orbit. The lunar extraterrestrial intensity is obtained by reflecting the solar intensity off of the moon's surface as in Reference 16.

$$\bar{I}_{\nu}^{MOON} = 2.04472 \times 10^{-7} \; \bar{I}_{\nu}^{SUN} \; \alpha_{\nu} \; P_{\gamma'}^{MOON}$$

Here α_{ν} is the wavenumber dependent geometric albedo of the moon[17,18] while $P_{\gamma'}^{MOON}$ is the moon's phase function giving the relative intensity as a function of the phase angle γ' of the moon.[19] Note that $P(\gamma' = 0) = 1$ for a full moon.

4.3 Verification of the Single Scattering Algorithm

To ensure that the single scattering algorithm was correctly implemented, LOWTRAN calculations were compared to calculations of single scattered radiance by an independent, well-developed model. This model is a modification of the

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15. Thekaekara, M.P. (1974) Extraterrestrial solar spectrum, 3000-6100 A at 1A intervals, Appl. Opt. 13.

16. Turner, R.E., et al (1975) Natural and Artificial Illumination in Optically Thick Atmospheres, Environmental Research Institute of Michigan, Report No. 108300-4-F.

17. Condron, T.P., Lovett, J.J., Barnes, W.H., Marcotte, L., and Nadile, R. (1968) Gemini 7 Lunar Measurements, AFCRL-68-0438, AD A678099.

18. Lane, A.P., and Irvine, W.M. (1973) Astron. J. 78.

19. Bullrich, K. (1948) Ber. Deutsch. Wettered, U.S. Zone No. 4.

plane-parallel, monochromatic multiple scattering code described in Reference 20. This model, based on the adding/doubling technique, was modified to compute only single scattered radiance. Since LOWTRAN gaseous transmission functions do not obey Beer's Law, gaseous absorption was deleted in the calculations by setting the gaseous transmittances in LOWTRAN equal to 1.0. Statements were added to LOWTRAN to calculate and write total optical depths and albedos based on the remaining attenuation mechanisms. This data was then used in the modified adding/doubling programs. Comparisons were limited to cases where both the solar and line-of-sight zenith angles were within the range where the plane parallel approximation is valid.

An example of the comparisons is shown in Table 1. The optical path in this case is from ground to space with a zenith angle of 12.95°, the solar zenith angle is also 12.95°. A Henyey-Greenstein phase function was used [see Eqs. (37) and (38)]. The total optical depth for the optical path from ground to space is 0.183. The table presents the ratio of the LOWTRAN scattered radiance to the single scattered plane-parallel calculation for asymmetry factors g of 0 and 0.8 and for relative azimuthal angles of 0°, 90°, and 180°. The radiances shown are the upward radiances at 100 km, both the upward and downward radiance at 2 km, and the downward radiance at the ground. In all cases, the LOWTRAN scattered radiance is within one percent of the radiance calculated by the adding/doubling program. This agreement demonstrates that the LOWTRAN single scattering algorithm has been properly implemented.

4.4 Phase Functions for Scattering by Atmospheric Aerosols and Molecules

The angular scattering of light by the atmosphere is specified by the phase function that gives the differential probability of the scattered radiation going in a given direction. The scattering by the aerosols and air molecules are treated separately using the appropriate phase function for each. The angular distribution from the two types of scattering are combined, weighted by the corresponding scattering coefficients.

The phase functions as used in the program are normalized so the integral over all possible scattering directions (that is, a sphere) is unity:

$$\iint_{4\pi} P(\gamma)\, d\,\Omega = 1 \qquad (36)$$

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20. Sharma, S. (1980) An Accurate and Computationally Fast Formulation for Radiative Fields and Heat Transfer in General, Plane-Parallel, Non-Grey Media With Anisotropic Scattering, PhD Thesis, University of Illinois at Chicago.

Table 1. Ratio of Single Scattered Radiance, LOWTRAN 6 to Adding/Doubling (See Text for a Detailed Description). The figure at the bottom illustrates the geometry

Top ↑ (100 km) g	0.0	0.8	ψ
	1.0022	1.0023	0°
		1.0024	90°
		1.0020	180°

(a)

2 km g	0.0	0.8	ψ
	1.0015 ↑	1.0014	0°
	1.000 ↓	1.000	
		↑ 1.0014	90°
		↓ .9962	
		↑ 1.0015	180°
		↓ .9907	

(b)

Bottom ↓ g	0.0	0.8	ψ
	1.0003	1.000	0°
		.9957	90°
		.9908	180°

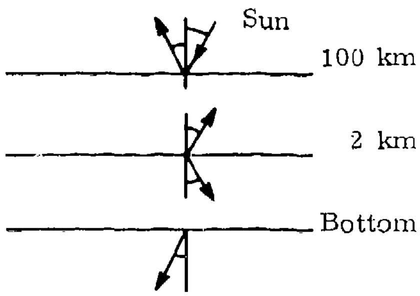
(c)

All zenith angles are 12.95°.

g = asymmetry factor

ψ = relative azimuth

↑ Radiation Propagation



with this normalization, $P(\gamma)\Delta\Omega$ is the fraction of the scattered radiation that is scattered into a solid angle $\Delta\Omega$ about an angle γ relative to the direction of the incident light.

4.4.1 AEROSOL ANGULAR SCATTERING FUNCTIONS

The LOWTRAN program offers the user three choices on handling the aerosol phase functions:

(1) They can use the standard phase functions stored in the program for the various aerosol models;

(2) They can use a Henyey-Greenstein type phase function, with a specified value for the asymmetry parameter;

(3) They can input their own phase functions for the different altitude regions.

4.4.2 STANDARD LOWTRAN PHASE FUNCTIONS

The standard aerosol phase functions stored in the LOWTRAN program correspond to the different aerosol models available within the LOWTRAN program. It is therefore recommended that this option be chosen whenever the LOWTRAN aerosol models are used for solar scattering. These standard phase functions were developed to approximate the exact phase functions, within about 20 percent, for any of the various aerosol models available in LOWTRAN as a function of wavelength, between 0.2 and 40 μm. The development of this standard set of approximate phase functions is discussed in Appendix D, along with details of their implementation in the LOWTRAN program.

The number of phase functions in this set represents a compromise between accuracy and memory requirements. The nominal accuracy of 20 percent is compatible with the other uncertainties in using the aerosol models (such as determining the concentration of the aerosols). If greater accuracy is desired in specifying the phase functions, the phase functions for all aerosol models, for a number of wavelengths, are provided as a supplemental data file on the LOWTRAN 6 tape. They are also tabulated and discussed in a separate report by Shettle et al.[21]

4.4.3 HENYEY-GREENSTEIN PHASE FUNCTION

In addition to the standard LOWTRAN phase functions corresponding to the different aerosol models built into LOWTRAN, the user has the option of specifying a Henyey-Greenstein scattering function be used. The Henyey-Greenstein[22] function is given by:

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21. Shettle, E.P., Abreu, L.W., and Moose, R. (1983) Angular Scattering Properties of the Atmospheric Aerosols, AFGL-TR-83- (to be published).

22. Henyey, L.G., and Greenstein, J.L. (1941) Diffuse radiation in the galaxy, Astrophys. J. 93:70-83.

$$P_{HG}(\gamma) = \frac{1}{4\pi} \frac{(1 - g^2)}{(1 - 2g \cos\gamma + g^2)^{3/2}} \quad , \tag{37}$$

where γ is the scattering angle and g is the asymmetry parameter,

$$g = \iint_{4\pi} \cos\gamma \, P(\gamma) d\Omega \quad , \tag{38}$$

with $P(\gamma)$ normalized as in Eq. (36). The asymmetry parameter gives a measure of the asymmetry of the angular scattering. It has a value of +1 for complete forward scattering, 0 for isotropic or symmetric scattering, and -1 for complete backscattering.

4.4.4 USER-DEFINED PHASE FUNCTIONS

The LOWTRAN code allows the user to input their own phase functions for the different altitude regions. These scattering functions can be defined at up to 50 different angles, as specified by the user. The same angles must be used for all four altitude regions.

When inputting their own phase functions the user should make sure they are normalized as in Eq. (36). The literature is not standard on this convention, and other conventions are used, the most common alternate form has the integral (36) equal to 4π.

4.4.5 MOLECULAR SCATTERING PHASE FUNCTION

The angular distribution of light scattered by the air molecules is described by the Rayleigh scattering phase function:

$$P(\gamma) = \frac{3}{16\pi} \cdot \frac{2}{2+\delta} \left[(1+\delta) + (1-\delta)\cos^2\gamma\right] \quad , \tag{39}$$

where δ is the depolarization factor that gives the correction for the depolarization effect of scattering from anisotropic molecules. When δ goes to zero, that is, no depolarization, or symmetric molecules, Eq. (39) reduces to:

$$P(\gamma) = \frac{3}{16\pi} \left[1 + \cos^2\gamma\right] \quad , \tag{40}$$

which is a commonly used approximation for the Rayleigh phase function.

A value of δ = 0.0295 (Kasten[23]) is used in Eq. (39). Young[24] has given a value of δ = 0.0279 for dry air based on more recent measurements. With all constants evaluated, Eq. (39) becomes

$$P(\gamma) = 0.06055 + 0.05708 \cos^2 \gamma \quad . \tag{41}$$

4.5 Sample Calculations

Figures 12 and 13 show some representative calculations from LOWTRAN using the single scattering option. In these figures, the solid line represents the radiance emitted by the atmosphere, the dashed line the path scattered radiance and the dotted line the ground reflected radiance (if any). The atmospheric profile in all cases is the 1962 U.S. Standard Atmosphere, and the Rural aerosol model with 10-km meteorological range (VIS = 10 km). The surface albedo is 0.05, independent of wavenumber corresponding to an emissivity of 0.95. The solar zenith angle is 45°; results are shown for relative path azimuth angles of both 0° and 180°. (See Appendix C for a discussion of the scattering geometry.)

In Figure 12, the observer is on the ground looking out to space with a zenith angle of 30°. The upper dashed line corresponds to a relative azimuth of 0° with a scattering angle of 15°, while the lower dashed line is 180° relative azimuth with a scattering angle of 75°. The figure shows that for the relative azimuth of 0°, the scattered radiance dominates everywhere above 2400 cm^{-1}, except around the strong CO_2 absorption band centered at 3700 cm^{-1}. For the relative azimuth of 180°, the scattered radiance is more than an order of magnitude less. This difference is due entirely to the difference in the scattering angles: the line-of-sight path and the scattering point-to-sun paths are otherwise identical. The reason for this difference is as follows: the bulk of the scattering occurs in the boundary layer where the rural aerosol model applies. The phase function for the rural aerosol model has a strong forward peak for these wavelengths. The large difference in the phase function between a scattering angle of 15° and 75° accounts for the large difference in the scattered radiance.

In Figure 13, the observer is at 100 km looking down at the earth with a zenith angle of 150° (this is the reverse of the path in Figure 12). Again the upper dashed line corresponds to the relative azimuth of 0° with a 105° scattering angle and the lower one corresponds to 180° relative azimuth with a scattering

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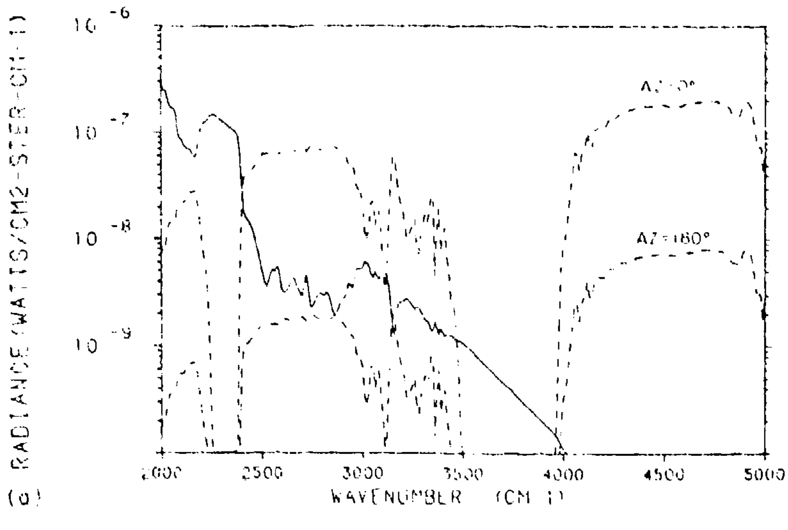
23. Kasten, F. (1968) Rayleigh-cabannes streuung in trockener luft unter beruecksichtigung neuerer depolarisations-messungen, Optik, 27:155-166.

24. Young, A.T. (1980) Revised depolarization corrections for atmospheric extinction, Appl. Opt. 19:3427-3428.



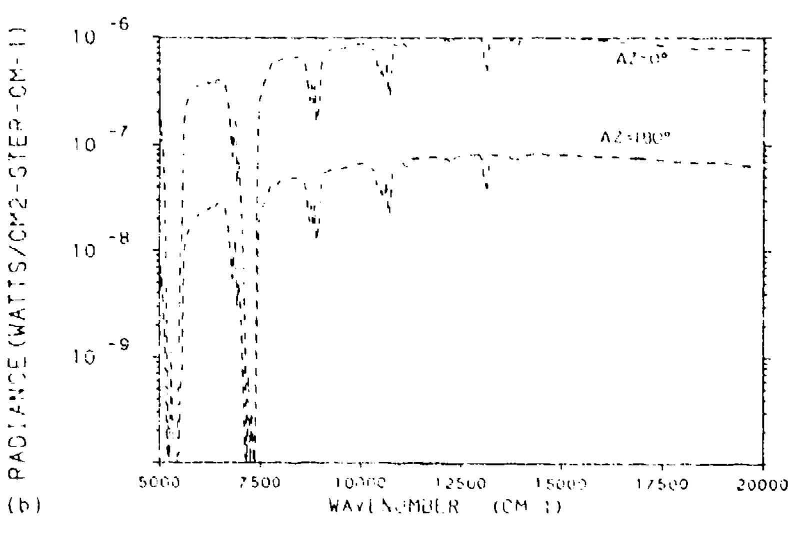


Figure 12. Calculated Radiances for the Following Conditions: Observer at the Ground Looking to Space With a Zenith Angle of 30°, Solar Zenith Angle of 45°, Relative Azimuths of 0° and 180°, U.S. Standard Atmosphere 1962, Rural Aerosol Model, VIS = 10 km. Solid line is atmospheric emission, dashed lines are path scattered radiances. (a) 2000 cm^{-1} to 5000 cm^{-1}, (b) 5000 cm^{-1} to 20000 cm^{-1}

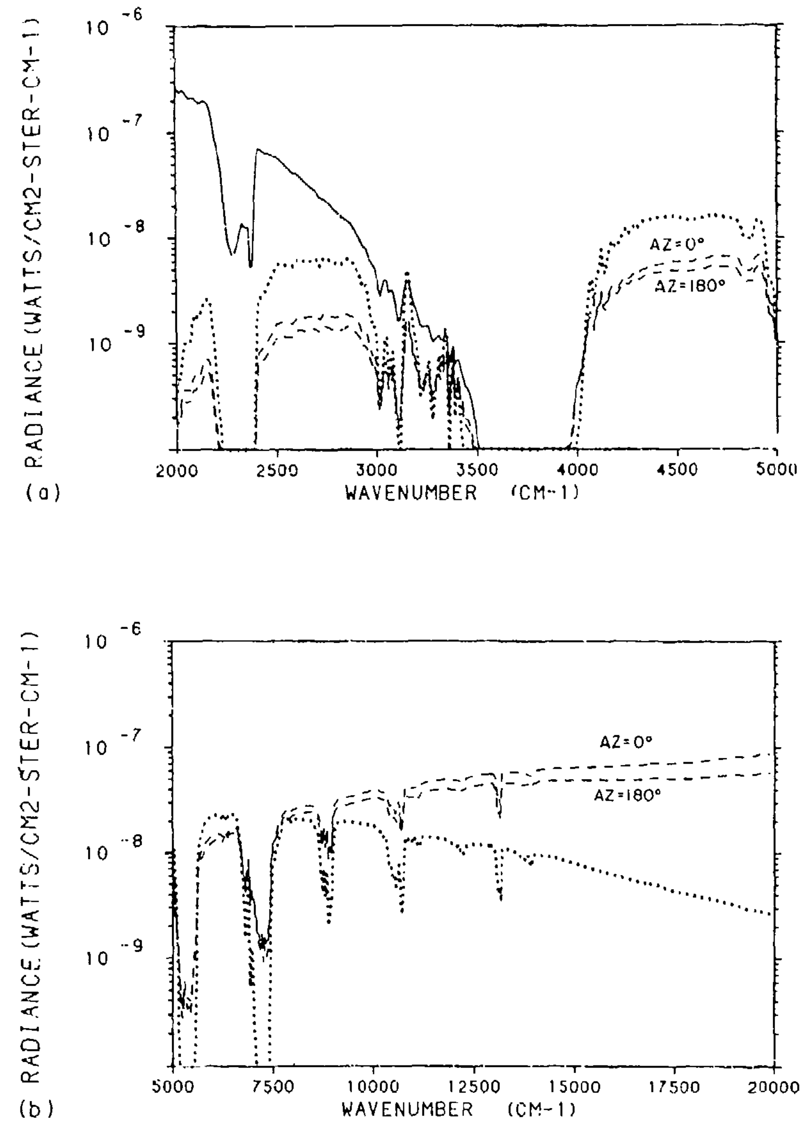


Figure 13. Calculated Radiances for the Following Conditions: Observer at 100 km Looking at the Ground With a Zenith Angle at 100 km of 150°, Solar Zenith Angle is 45°, Relative Azimuths of 0° and 180°, Ground Albedo of 0.05, U.S. Standard Atmosphere 1962, Rural Aerosol Model VIS = 10 km. Solid line is atmospheric emission, dashed lines are path scattered radiances, dotted line is ground reflected radiance. (a) 2000 cm^{-1} to 5000 cm^{-1} and (b) 5000 cm^{-1} to 20000 cm^{-1}

angle of 165°. In this case the ground reflected solar radiance is greater than the path scattered radiance below 5000 cm^{-1} and greater than the atmospheric emission above 4000 cm^{-1}. The path scattered radiances for the two relative azimuths are now quite similar since the difference in the phase function between 105° and 165° is small. In the visible (~ 17500 cm^{-1}) the ground reflected radiance is more than an order of magnitude less than the path scattered radiance so that the ground is effectively obscured by the haze above it. Note, however, that the assumed albedo 0.05 is low for the visible region of the spectrum.

4.6 Recommendations on Usage

The inclusion of single scattered solar radiance in LOWTRAN 6 is a significant improvement over previous versions that calculated the atmospheric emission only. The single scattering approximation is valid over a broad range of conditions found in the atmosphere. However, there are also conditions of interest in the atmosphere where multiple scattering and/or internal sources must be included to accurately calculate the atmospheric radiance. There is no simple indicator that predicts the conditions for which the single solar scattering approximation is acceptable: rather the range of applicability depends upon a large set of parameters including the atmospheric profile, the optical path, the solar geometry, the aerosol phase function, and the wavenumber region. The user will find some guidance in Section 4 of Ridgway et al.[14] The following general comments, in part drawn from this source, may be useful. However, the user must be aware that they may not apply in all cases and are indicative only. Also, these comments apply only to the validity of the single scattering approximation and not the uncertainties in the atmospheric data.

1. The single scattering approximation always underestimates the scattered radiance compared to multiple scattering.

2. The single scattering approximation becomes less valid with increasing scattering optical depth and with increasing single scattering albedo. For a scattering optical depth of less than about 0.7, the ratio of multiply scattered to singly scattered radiances should be less than 1.5. For scattering optical depths greater than about 2, the ratio may be much larger.

3. For an observer in space looking down at the ground in a window region where the total optical depth is less than 2, the ratio of multiply scattered to singly scattered radiance is in most cases less than 2.0 and in many cases less than 1.5. And contrary to intuition, the ratio decreases as the solar zenith angle increases and/or the path zenith angle decreases (note: a path zenith angle of 180° is straight down).

4. For an observer at the ground, the ratio of multiple to single scattered radiance <u>increases</u> with both the path and the solar zenith angle, and in general, single scattering is a poor approximation (error greater than a factor of 2) for cases where both the zenith angles are greater than 70.

5. Multiple scattering effects are dominant in clouds and thick fogs.

6. Single scattering is a good approximation for early twilight cases, that is, where the sun is just below the horizon. For late twilight cases, multiple scattering becomes significant.

7. Single scattering is a good approximation when looking near the sun, since the scattering is dominated by the large forward peak.

8. In general, the aerosol scattering optical depth increases with wavenumber so that scattering in the infrared is less than that in the visible.

From a purely mechanical point-of-view, the single scattering option should not be used along with either the cirrus cloud model, or the rain model since the program does not compute the scattered radiance from these aerosols. For an optical path looking directly at the sun, the single scattering model includes only the scattered radiance, and not the transmitted solar radiance.

4.7 Directly-Transmitted Solar Irradiance

An additional option has been provided to allow the user to compute the directly transmitted solar irradiance (flux), that is, the irradiance measured by an observer looking directly at the sun. This irradiance is given by:

$$\bar{I}_\nu = \bar{I}_\nu^{SUN} \, \bar{\tau}_e^{A+M} \quad . \tag{42}$$

Note that all scattered light is lost and that no scattering into the path is included. Instructions for using this option are in Section 10.2.3.2.

An example of the directly transmitted solar irradiance is given in Figure 14. The dashed line is the solar irradiance at the top of the atmosphere. The solid line is the transmitted irradiance for a vertical path from the ground, for the U.S. Standard Atmosphere 1962 and no aerosol extinction.

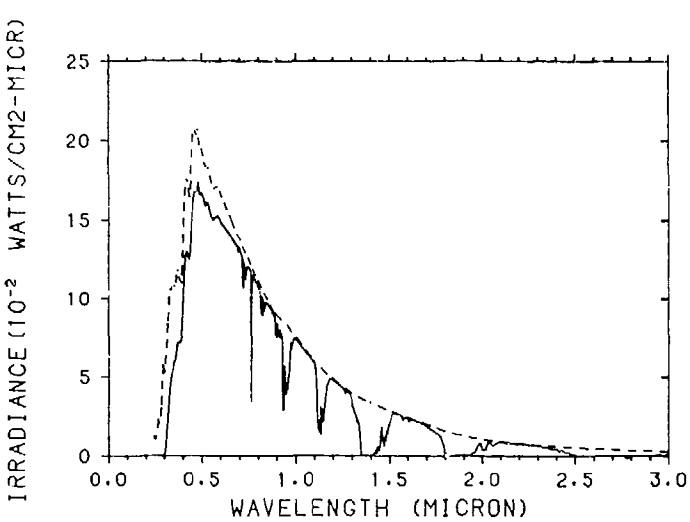


Figure 14. Solar Radiance (Dashed Line) and Directly Transmitted Solar Irradiance (Solid Line) for a Vertical Path, From the Ground, U.S. Standard Atmosphere 1962, No Aerosol Extinction

5. NAVY MARITIME AEROSOL MODEL

S.G. Gathman, Naval Research Laboratory, Washington, DC

This chapter provides a brief description of the Navy maritime aerosol model and its implementation in LOWTRAN. A complete discussion of the model is given by Gathman.[25] Since this model includes an explicit dependence on wind speed it is recommended that it be used instead of the LOWTRAN 5 maritime model, which assumed moderate wind speeds (Shettle & Fenn).[26] The latter model is retained in LOWTRAN 6 for comparison purposes.

5.1 Description of the Model

The aerosol population found over the world's ocean is significantly different in composition and distribution from that of a continental origin. These aerosol are largely derived from the sea. They are produced by the evaporation of sea spray and from jet and film droplets. Jet droplets are ejected into the air by the bursting of small air bubbles at the sea surface. The bursting of the bubble film leaves behind many smaller film droplets that may also be diffused into the air.

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25. Gathman, S.G. (1983) Optical properties of the marine aerosol as predicted by the Navy aerosol model, Opt. Eng. 22:57-62.

26. Shettle, E.P., and Fenn, R.W. (1979) Models of the Aerosols of the Lower Atmosphere and the Effects of Humidity Variations on Their Optical Properties, AFGL-TR-79-0214, AD A085951.

These mechanisms are wind dependent and require whitewater phenomenon in order to produce aerosol.

Once the aerosol droplets are airborne, they undergo additional sorting and mixing processes. The marine boundary layer is usually capped by a temperature inversion and, within this boundary layer, the smaller marine aerosol together with any background aerosol form a fairly uniform aerosol spatial distribution. Once introduced into the atmosphere the lifetime of an aerosol particle is dependent on the size of the particular aerosol particle. Those with very small sizes have a very long residence time in the boundary layer if there are no washout processes taking place. On the other hand, those with very large sizes have a short residence time and do not contribute to the stationary long-term aerosol population.

The Navy maritime aerosol model differentiates between these various types of aerosol by postulating that the marine atmosphere is composed of three distinct populations each of which is described by a lognormal size distribution. The parameters that describe the analytical form of the size distribution are then related to both recent meteorological history and current meteorological observations.

The smallest component of the model is a "continental" component. This is the background aerosol and although it apparently has little to do with current wind parameters, it is dependent on the elapsed time required for the air mass to traverse the sea from the continent to the point of observation. Quantification of this component in terms of routine meteorological measurements is difficult, but for convenience an integer from 1 to 10 is used to specify the ICSTL parameter, which gives a qualitative indication of the continental contribution: a value of 1 representing relatively pure maritime aerosol, and a value of ICSTL = 10 meaning a significant continental component.

The second component, the "stationary" component of the maritime aerosol, is the part of the maritime aerosol that depends on the current and past history of the wind and represents that portion of the spectra that are produced by the high wind and whitewater phenomenon but do not fall out rapidly. The amplitude of this component is related to the average wind speed over the past 24 h, and is specified by the WHH parameter.

The third or "fresh" component of the Navy aerosol model is a lognormal population of aerosol that is related to the current wind speed (specified in the program by the WSS parameter). The amplitude of this component is a function of the current wind speed and reflects the current action of the production of drops produced by whitewater as a result of wind wave actions.

The amplitudes of both the second and third components of the aerosol population reflect the necessity of wind speed being above a certain minimum value

before whitewater phenomena are observed and thus, marine aerosol produced. This minimum value is 2.2 m/s.

The model is also responsive to the current relative humidity. It is well known that particles composed of sea salt are hygroscopic and change their composition and size as a function of the relative humidity. The model uses the "swelling factor" proposed by Fitzgerald,[27] which adjusts the mode radii of the three components of the model, but does not alter the total number of particles that are airborne. The model also adjusts the complex index of refraction of the aerosol based on the volume weighted method of Hanel,[28] using the refractive index of soluble aerosol (Volz)[29] for the dry component and that of pure water from Hale and Querry.[30]

5.2 Use of the Navy Maritime Model

As discussed in the preceding section, this model requires three parameters to be specified in addition to those used by the other aerosol models (that is visibility and relative humidity). These additional parameters are: (1) ICSTL, which indicates the degree of continental influence, (2) WHH, the average wind speed over the past day, and (3) WSS, the current wind speed. The LOWTRAN program will use default values for any unspecified parameter.

Three methods can be used to estimate ICSTL. The first is by plotting the air mass trajectory and determining the elapsed time, t, since the air parcel left land. This time is related to ICSTL by the following empirical equation:

$$\mathrm{ICSTL} = \mathrm{INT}(9\exp[-t(\mathrm{days})/4]+1) \quad , \tag{43}$$

where INT(x) truncates to the nearest integer less than x.

Secondly, if measurements of the current radon 222 concentrations in the atmosphere are available (Larson and Bressan),[31] then the air mass parameter can be estimated by the formula:

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27. Fitzgerald, J.W. (1978) On the Growth of Aerosol Particles With Relative Humidity, NRL Memo Rpt. 3847.
28. Hanel, G. (1971) New results concerning the dependence of visibility on relative humidity and their significance in a model for visibility forecasts, Contrib. Atmos. Phys. 44:137-167.
29. Volz, F.E. (1972) Infrared refractive index of atmospheric aerosol substances, Appl. Opt. 11:755-759.
30. Hale, G.M., and Querry, M.R. (1973) Optical constants of water in the 200 nm to 200 micrometer wavelength region, Appl. Opt. 12:555-563.
31. Larson, R.E., and Bressan, D.J. (1980) Air mass characteristics over coastal areas as determined by radon measurements, Preprint of Second Conference on Coastal Meteorology, 30 January - 1 February 1980, Los Angeles, Calif.; published by A.M.S., Boston, Mass.

$$ICSTL = INT(Rn/4) + 1 \quad , \tag{44}$$

where Rn is the concentration of radon 222 in pCi/m^3. This relationship can be used because radon 222 is introduced into the atmosphere only by processes occurring over land. Therefore, since this radioactive substance has a half-life of 3.86 days, the concentration of radon 222 is then related to the time since the air parcel left the land.

A third method for determining ICSTL consists of subjectively choosing an integer between 1 and 10 to determine the "quality" of the air mass, with a value of "1" being for pure oceanic air and a value of "10" if the air has recently been ashore over a polluted industrial area. Values in between can be used to specify the various grey areas between these two extremes.

If the user does not input a value for the parameter ICSTL, the LOWTRAN code will use a default value of ICSTL = 3.

The current wind speed, WSS, and the average wind speed over the past 24 h, WHH, should be input in units of m/s. If the average wind speed is input as 0 or is given a negative value, a default value will be chosen that depends on the model atmosphere being used, (specified by the parameter MODEL). These default wind speeds are shown in Table 2. These default wind speeds are based on average values for observations made in the indicated region, except for the user-defined cases (MODEL = 0 or 7), which use a global mean value. If the current wind speed, WSS, is not specified, it is set equal to the average wind speed, WHH.

Visibility observations at sea are usually only estimates because of the lack of targets at fixed distances from the observer. Therefore, it is suggested in the use of this model that, unless visibility is measured accurately, the default

Table 2. Default Wind Speeds for Different Model Atmospheres

MODEL	Model Atmosphere	Default Wind Speed (m/s)
0	User-defined (Horizontal Path)	6.9
1	Tropical	4.1
2	Midlatitude summer	4.1
3	Midlatitude winter	10.29
4	Subarctic summer	6.69
5	Subarctic winter	12.35
6	U.S. Standard	7.2
7	User-defined	6.9

visibility condition be used because user-specified visibility inputs adjust all of the extinction and absorption coefficients in the calculations in order to force the calculated extinction at 0.55 μ to agree with the visibility and, if inaccurate, may introduce excessive error into the calculations.

The Navy model is designed to operate accurately within certain limits of input parameters. While parameter values outside of these limits are permitted by the overall LOWTRAN 6 program, the accuracy of the predictions outside of these limits is reduced. The design limits of the model parameters are:

$$50 \text{ percent} \leq \text{Relative Humidity} \leq 98 \text{ percent}$$
$$0 \text{ m/s} \leq \text{WSS} \leq 20 \text{ m/s}$$
$$0 \text{ m/s} \leq \text{WHH} \leq 20 \text{ m/s}$$

and

$$0.8 \text{ km} \leq \text{VIS} \leq 80 \text{ km} \quad .$$

For relative humidities or wind speeds outside these design limits the program will internally reset the value to the nearest limit, rather than try to extrapolate the aerosol properties.

5.3 Sample Results

This section briefly presents some sample results of transmittance calculations using the maritime aerosol model. Figure 15 shows the transmittance for a 10-km horizontal path at the surface, for each of the standard model atmospheres in LOWTRAN. These calculations were all done using the default values for all the parameters. Thus, ICSTL was set to 3, the wind speed depended on the model atmosphere (see Table 2), and the maritime aerosol model calculated the visibility based on the aerosol properties with these parameter values and the relative humidity for the model atmosphere. The values of the parameters for these different cases are summarized in Table 3.

The differences in the transmittances shown in Figure 15 are due both to variations in the aerosol properties for different atmospheric conditions and to the different amounts of water vapor in the various model atmospheres. The transmittance in the 3 through 5 μm (2000 through 3300 cm^{-1}) window is more sensitive to changes in the aerosol properties and in the 8 through 13 μm (750 through 1250 cm^{-1}) window, the transmittance is more sensitive to the variations in the water vapor.

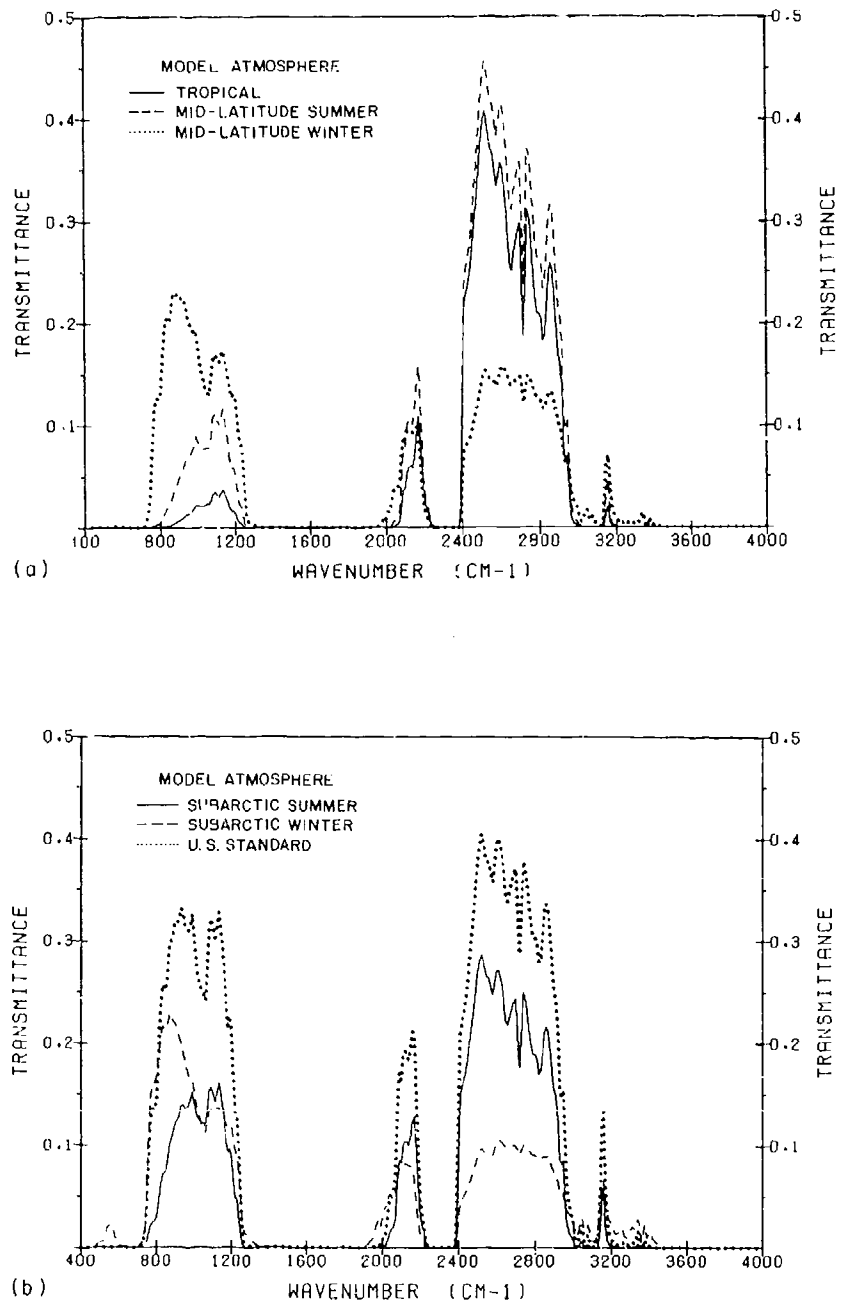

Figure 15. Atmospheric Transmittance for a 10-km Horizontal Path at the surface With the Navy Maritime Aerosol Model. (a) for the tropical, midlatitude summer, and midlatitude winter model atmospheres and (b) for the subarctic summer, subarctic winter, and U.S. Standard atmospheres

Table 3. Conditions for Sample Runs of the Navy Maritime Aerosol Model

MODEL	Atmosphere	Wind (m/s)	Rel Hum (percent)	Vis (km)	ρH_2O (gm/m^3)
1	Tropical	4.10	73	49.4	19.0
2	Midlatitude summer	4.10	70	52.2	14.0
3	Midlatitude winter	10.29	71	17.8	3.5
4	Subarctic summer	6.69	72	28.3	9.1
5	Subarctic winter	12.35	73	14.2	1.2
6	U.S. Standard	7.2	49	39.5	5.9

6. ARMY VERTICAL STRUCTURE ALGORITHM

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White Sands Missile Range, New Mexico

6.1 Introduction

An algorithm for modeling the vertical structure of aerosols has been added to the LOWTRAN 6 code. It was developed initially to describe the vertical distribution of the atmospheric aerosols for conditions of limited visibility and beneath low-lying stratus cloud decks.[32] The formalism has been extended so it can also represent cases with no cloud ceiling and moderate to high visibility.[33] The algorithm will generate the vertical aerosol profile within the boundary layer from input parameters, such as surface visibility and the cloud ceiling height. This model is designed for use within the lowest 2 km of the atmosphere.

6.2 The Vertical Profile Model

In low visibility situations, due either to haze or fog, increasing numbers of observations show that the measured visibility at the surface is not representative of conditions a few hundreds of meters, or even tens of meters, above the surface. Thus, the "slant path visibility" can be significantly different from the "horizontal visibility". In a significant fraction of the cases the visibility becomes worse as the height above the surface increases. These cases are of special concern here.

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32. Heaps, M.G. (1982) A Vertical Structure Algorithm for Low Visibility/Low Stratus Conditions, ASL-TR-0111, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex.

33. Heaps, M.G., and Johnson, R.D. (1983) An Empirical Algorithm for the Vertical Structure of Atmospheric Extinction, ASL-TR-0142, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex.

Detailed data on the vertical structure of fogs and hazes have been gathered in the Federal Republic of Germany on several different occasions.[34,35] Droplet size distributions in the 0.5- to 47-μm range have been measured from a balloon-borne instrument, thus yielding vertical profiles.[36] Extinction coefficients at desired wavelengths or the liquid water content can be calculated from these measured droplet size distributions.

The vertical structure of these profiles has been examined previously by Duncan et al,[37] who characterized the vertical structure in the form

$$y = a' x + b' \quad , \tag{45}$$

where $x = \log_{10} k(z)$, $y = \log_{10} k(z + 20)$, a' and b' are coefficients that were chosen to fit the data, and $k(z)$ is the value of the extinction coefficient at the altitude z; $k(z + 20)$ is then the value of this variable at an altitude of $z + 20$ m. Thus, one can work stepwise from the surface up through the cloud boundary layer. Figure 16 shows the fit of Eq. (45) to the data. It should be noticed that there is a sharp change in slope at a value of about 7.1 km^{-1} for the extinction. The physical significance of this inflection point is discussed below.

The point of intersection of the two line segments physically represents the changes in extinction due to changes in the state of particle growth as one moves from a subsaturated environment (lower line segment), where relative humidities are less than 100 percent, to a supersaturated environment, (upper line segment). Thus, this point of intersection will be taken to represent the cloudbase or lower cloud boundary.

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34. Lindberg, J.D. (1982) Early Wintertime Fog and Haze. Report on Project Meppen 80, ASL-TR-0108, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex.

35. Hoihjelle, D.L., Pinnick, R.G., Lindberg, J.D., Loveland, R.B., Stenmark, E.B., and Petracca, C.J. (1976) Balloon-borne Aerosol Particle Counter Measurement Made in Wintertime at Grafenwohr, West Germany, ECOM-DR-76-3, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex.

36. Pinnick, R.G., Hoihjelle, D.L., Fernandez, G., Stenmark, E.B., Lindberg, J.D., Jennings, S.G., and Hoidale, G.B. (1978) Vertical Structure in Atmospheric Fog and Haze and Its Effect on IR Extinction, ASL-TR-0010, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex.

37. Duncan, L.D., Lindberg, J.D., and Loveland, R.B. (1980) An Empirical Model of the Vertical Structure of German Fogs, ASL-TR-0071, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex.

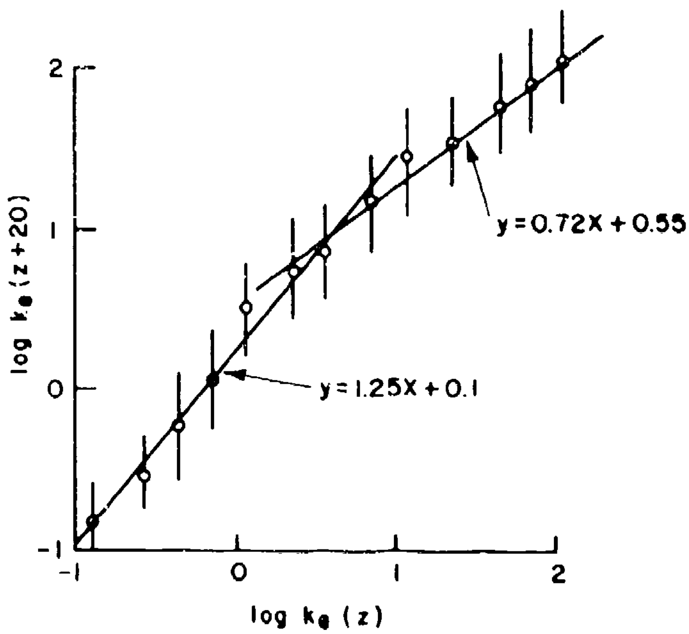

Figure 16. Relationship Between the Extinction Coefficient (at 0.55 μm) at Altitudes z and z + 20 m. The vertical lines are the error bars for the data (after Duncan et al)[37]

Since $x = \log_{10} k(z)$ in Eq. (45) and y is really just $x + \Delta x$ over an altitude interval Δz, the relation for the extinction as a function of altitude can be expressed as[32]

$$k_e(0.55\ \mu m) = A \exp[B \exp(Cz)] \quad , \tag{46}$$

where A, B, and C are functions of preselected boundary values, the initial or starting value of extinction, and the cloud ceiling height. Note that since there are two straight line segments, the coefficients A, B, and C have different values, depending on which part of the data curve in Figure 16 is being followed.

The rate at which the extinction changes with altitude below the cloudbase actually depends on the cloud ceiling height z_c. The lower line segment in Figure 16 represents an average of several sets of data and therefore gives a single,

average value for the coefficient C in Eq. (46). The explicit dependence of C on the cloud ceiling height can be incorporated by defining the coefficient C as

$$C = \frac{1}{z_c} \ln \left[\frac{\ln(E/A)}{\ln(D/A)} \right] , \tag{47}$$

where E is the value of the extinction at the cloudbase, D is the observed value of extinction at the surface, and A is the same coefficient used in Eq. (46). In this case A is the lower limit to the extinction in the hazy/foggy region below the cloud. Figure 17 shows the visible extinction coefficient plotted as a function of altitude for the same initial surface value, but several different cloud ceiling heights. The solid line represents the (average) values from the line segments in Figure 16. The dashed vertical line represents the value of the extinction for the cloudbase given by the intersection of the line segments in Figure 16. The solid line to the right of the dashed vertical line represents the extinction profile inside the cloud and can be appended to any one of the vertical profiles to the left.

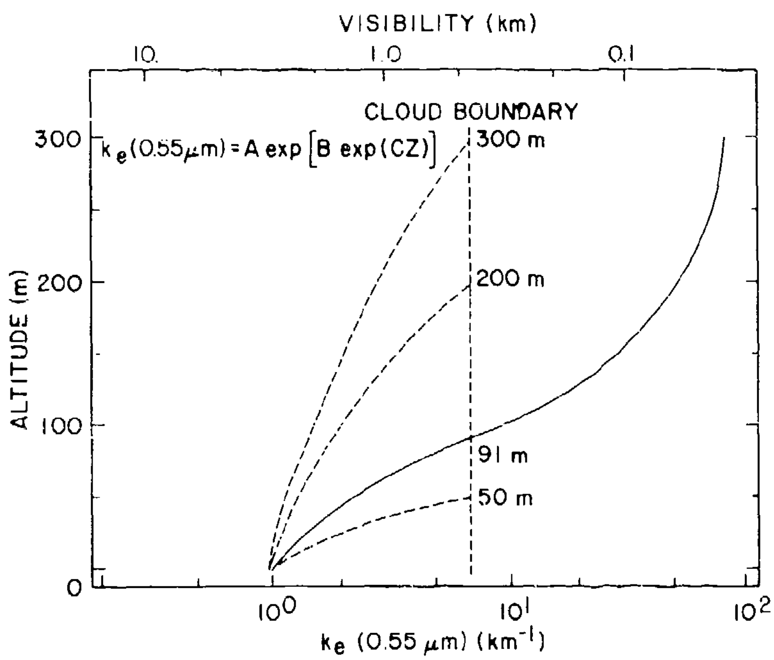

Figure 17. The Vertical Profile of the 0.55-μm Extinction Coefficient for Various Cloud Ceiling Heights. The solid line shows the average profiles from Figure 16, the dashed vertical line represents the value at the cloud boundary

Initially the algorithm for the vertical structure of hazes, fogs, and clouds represented by Eq. (46) was developed for low visibility/low stratus conditions and is based on inputs of the surface meteorological range (extinction coefficient) and the cloud ceiling height. This algorithm has now been extended to cases where there may be no cloud ceiling and where the extinction coefficient decreases with increasing altitude.[33]

6.3 Applicability of the Vertical Structure Algorithm

Three initial visibility conditions are considered. The first condition is for stratus clouds and thick fogs (which in this instance may be treated as a cloud at the ground); the second condition is for hazes and fog; and the third condition is for the clear to hazy atmosphere. The vertical structure of visibility can be represented by four different types of curves as illustrated in Figure 18. Curves 1 and 2 represent the cases where the extinction coefficient increases (that is, visibility degrades) with increasing altitude; these cases are representative of the vertical structure of extinction for thick fogs or for low visibility/low stratus conditions. Curves 3 and 4 represent cases where the extinction coefficient decreases (that is, visibility improves) with increasing altitude. Each of these cases will now be briefly outlined.

Case 1: This curve is to be used for dense fogs at ground level or when one is at the cloudbase or in the cloud. Physically this curve represents the increase in liquid water content (LWC), and consequently the increase in extinction coefficient and decrease in visibility, of a saturated parcel of air rising at the wet adiabatic lapse rate. This curve should be used only when the initial extinction coefficient (or meteorological range) is in the thick fog/cloud region shown between the two dashed lines representing boundary values on the right-hand side of Figure 18.

Case 2: This curve is to be used for low visibility conditions beneath the clouds due to haze or fog when there is a low cloud ceiling present.

Case 3: This curve is to be used when there is a shallow radiation fog present or when a haze layer is capped by a distinct (low-lying) temperature inversion. A cloud ceiling is not present.

Case 4: This profile is to be used for cases where there is reasonable vertical homogeneity for visibility in a clear to slightly hazy atmosphere that may have a shallow haze layer near the surface. A cloud ceiling is not present.

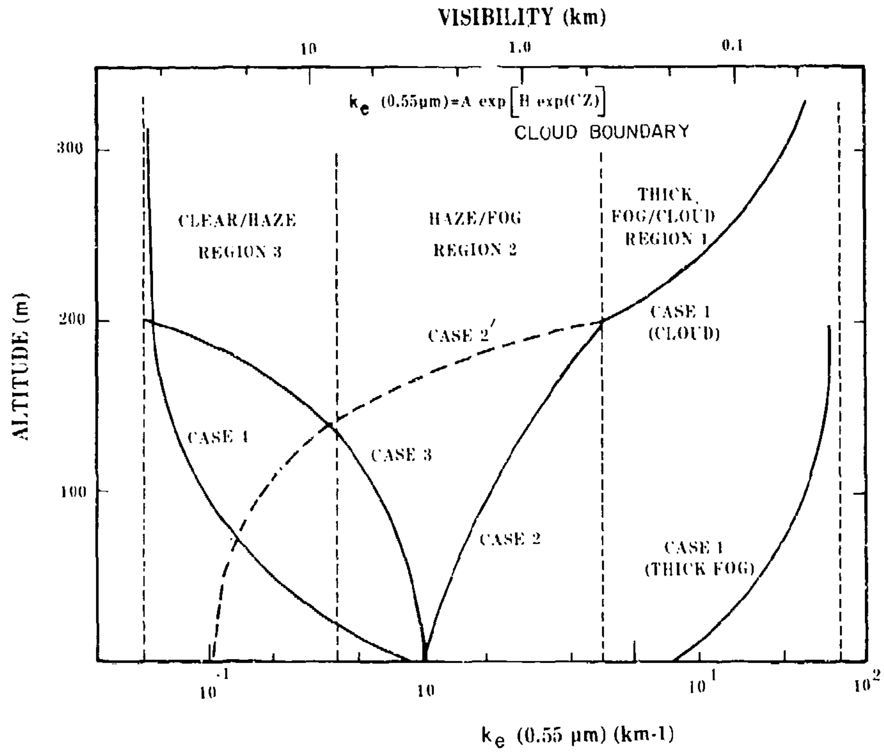

Figure 18. Four Different Cases Represented by the Vertical Structure Algorithm

Profiles of the 0.55-μm extinction coefficient are shown in Figure 18 for these different cases. Two examples of representative profiles are shown for case 1. The first example is for a thick fog at the surface, which is represented by an extinction coefficient profile that increases with height. When the depth of the fog is not known (which is usually the case because the sky is obscured), a default depth of 200 m is recommended. The second example is for a low-lying stratus cloud; for illustration the cloud ceiling height is taken to be 200 m. This profile should only be used from the cloudbase to the cloud top. Again, cloud thickness is usually not a measured quantity, and a default value of 200 m is recommended. The two examples shown here are actually the same profile one starting at the surface for the thick fog and the other starting at the cloud base of a low-lying stratus cloud. Within region 1, thick fog/cloud, only profiles of the case 1 type should be used. For a dense, shallow radiation fog, use a profile for case 3 as described below.

A representative profile for the structure beneath a stratus cloud is shown for case 2. In this instance the visibility conditions at the surface are representative of region 2, haze/fog, and the cloud ceiling height is 200 m. The slope and shape of the vertical structure profile beneath the cloud deck are a function of the initial value of the (surface) visibility and the cloud ceiling height. For haze/fog conditions when a cloud ceiling height less than 2 km is present, a profile of the case 2 type should always be used.

Often a low-lying cloud cover is present when the surface visibility is clear to only slightly hazy. In this instance a vertical structure profile similar to case 2 is appropriate. This profile is denoted as case 2' and is shown in Figure 18 as an alternate profile for the instance of a 200-m cloud ceiling height. The only difference between case 2 and case 2' is the manner of choosing the value of the coefficient A, which in turn influences the shape of the vertical profile.

A shallow radiation fog or a haze layer bounded by a temperature inversion can be represented by a vertical structure profile as shown in Figure 18 for case 3. The boundary layer heights for such occurrences are often difficult to estimate. Temperature inversion heights can be obtained from acoustic sounders or radiosonde observations; often visual sightings can be used to estimate depths of shallow fogs or haze layers. A nominal boundary layer height of 200 m has been selected for illustrative purposes. For radiation fogs where the depth is not known, a default value of 200 m is selected*; for inversion layers where the height of the inversion or boundary layer is not known, a default value of 2 km is selected.

Case 4 is represented by a profile for the condition where the vertical structure is essentially constant with altitude, with the exception of the lowest hundred meters of the boundary layer. An appropriate default value is the nominal background value for the 0.55-μm extinction coefficient for the fair weather case. Numerous observations have shown that the extinction coefficient is essentially constant within the planetary layer for well mixed conditions. Setting the coefficient C equal to zero in Eq. (46) will cause the algorithm to default to the observed surface value while providing a constant vertical profile.

Table 4 gives the tabular values of the 0.55-μm extinction coefficients that are to be used as boundary values for the different cases in their respective regions of applicability.

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*Note added in Proof. A more realistic value for radiation fogs is about 50 m. To override the default value in the program, read in the depth of the radiation fog for this case with ZINVSA = 0.05 km (see Section 10.2.2.1, page 90).

Table 4. Summary of the Conditions and Parameter Values for Different VSA Cases
k_e (0.55 μm) = A exp [B exp (Cz)]

	Case 1 (B < 0, C < 0)	Case 2 (B > 0, C > 0)	Case 2' (B > 0, C > 0)	Case 3 (B < 0, C > 0)	Case 4 (B > 0, C < 0)
Range of k	7.1 - 92 km^{-1}	0.40 - 7.1 km^{-1}	0.05 - 0.40 km^{-1}	0.05 - 7.1 km^{-1}	0.05 - 7.1 km^{-1}
Region of applicability	thick fog/clouds (ceiling obscured)	haze/fog ceiling < 2000 m	clear/haze ceiling < 2000 m	no ceiling, or ceiling > 2000 m, distinct low-lying inversion or boundary layer	no ceiling, or ceiling > 2000 m, no inversion or boundary layer
Surface visibility (that is, meteorological range)	Visibility ≤ 0.5 km	Visibility ≈ 0.5-10 km	Visibility > 10 km	Visibility > 0.5 km	Visibility > 0.5 km
A	92 km^{-1}	0.40 km^{-1}	0.9 × D	1.1 × D	0.05 km^{-1}*
B	ln (D/A)	ln (D/A)	ln (D/A)	ln (D/A)	ln (D/A)
C	-0.014 m^{-1}	$\frac{1}{Z_c} \ln \left[\frac{\ln(E/A)}{\ln(D/A)}\right]$	$\frac{1}{Z_c} \ln \left[\frac{\ln(E/A)}{\ln(D/A)}\right]$	$\frac{1}{Z_b} \ln \left[\frac{\ln(E/A)}{\ln(D/A)}\right]$	-0.015 m^{-1} (default value)
D	initial value at surface or at cloud boundary (note D < A)	initial value at surface (note D > A)	initial value at surface (note D < 0.4 km^{-1})	initial value at surface (note D < A)	initial value at surface (note D > A)
E	(not used)	7.1 km^{-1}	7.1 km^{-1}	0.05 km^{-1}*	(not used)
Z_c	(not used)**	ceiling height (m)	ceiling height (m)	inversion or boundary layer height (m)	(not used)

*A nominal background value for the lower troposphere.
**When the fog or cloud depth is not known (usually the case), the algorithm should be used only up to 200 m above the surface or cloud boundary (a default value for the stratus cloud thickness).

6.4 Implementation of the Vertical Structure Algorithm in LOWTRAN6

The operation of the Vertical Structure Algorithm (VSA) is controlled by three parameters, in addition to the Meteorological Range at the surface (VIS) and type of aerosol (IHAZE) for the boundary layer. These three additional parameters are: the cloud ceiling height (altitude of the cloud base), the thickness of the cloud or fog, and the height of the inversion or boundary layer, ZCVSA, ZTVSA, and ZINVSA respectively. The type of aerosol vertical profile generated depends on the values input for these parameters. The different cases or profile types selected are summarized in Table 5. Note that the value of ZINVSA will be ignored unless ZCVSA < 0.

The VSA defines the aerosol extinction at nine heights, from the ground to the top of the cloud (ZCVSA + ZTVSA) or the top of the boundary layer (ZINVSA). Ten meters above this cloud-top or boundary-layer level, the aerosol profile reverts to the standard LOWTRAN aerosol vertical distribution (or the user-supplied profile for a MODEL = 7 case). For these nine heights the air pressure, temperature, and the ozone concentration are found by interpolation from the model atmosphere indicated by the parameter MODEL (see the user instructions, Section 10).

The relative humidity for the LOWTRAN model atmospheres does not consider the presence of clouds (that is, all the model atmospheres have RH ≤ 80 percent at all altitudes). To correct for this, the VSA estimates the relative humidity as a function of the visible ($\lambda = 0.55\ \mu m$) extinction for the nine levels:

$$RH(z) = \begin{cases} 86.407 + 6.953 \cdot \ln[k_e(z)] & , \quad k_e < 7.064\ \text{km}^{-1} \\ 100\% & , \quad k_e \geq 7.064\ \text{km}^{-1} \end{cases} \tag{48}$$

If the user inputs their own relative humidity profile (MODEL = 7), that will be used instead of Eq. (48).

Table 5. Data Inputs and Default Values for the Different VSA Cases

Case	Selected by	Defaults (Used if the indicated parameter = 0)
1. Fog	VIS $\leq$ 0.5 km, ZCVSA $\geq$ 0	ZCVSA = 0, ZTVSA = 0.2 km
2. Haze/light Fog Below Cloud	0.5 < VIS $\leq$ 10 km, ZCVSA $\geq$ 0	ZCVSA depends on VIS ZTVSA = 0.2 km
2'. Moderate/high Visibility Below Cloud	VIS > 10 km, ZCVSA $\geq$ 0	ZCVSA = 1.8 km ZTVSA = 0.2 km
3. Radiation Fog/haze Layer, No Low Cloud	VIS > 0.5 km, ZCVSA < 0, ZINVSA $\geq$ 0	$\text{ZINVSA} = \begin{cases} 0.2 \text{ RAD FOG} \\ \text{If (VIS} < 2.0 \text{ km or IHAZE} = 9) \\ 2.0 \text{ Haze} \\ \text{If (VIS} > 2.0 \text{ km and IHAZE} \neq 9) \end{cases}$
4. No Boundary Layer or Low Cloud	VIS > 0.5 km, ZCVSA < 0, ZINVSA $\geq$ 0	

7. CIRRUS CLOUD MODEL

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7.1 Introduction

This section of the report describes the development of a cirrus cloud transmittance model and computer subroutine for use with LOWTRAN. Previous measurements and models of cirrus optical transmittance[38-44] have indicated large variations in the attenuation coefficient for cirrus in the near ultraviolet, visible, and infrared spectral regions. In the model developed here, the cirrus attenuation coefficient is shown to be proportional to the cloud thickness and independent of wavelength from the ultraviolet, 0.317-μm, to the infrared, 10-μm atmospheric window. The model is discussed, worldwide cirrus statistics are presented, and thickness statistics are tabulated.

7.2 Worldwide Cirrus Climatologies

A comprehensive study of worldwide cloud statistics has been done by Chang and Willand.[45] Their study used reports of the surface-based observer in recording the presence or absence of high clouds. However, as pointed out by Stone,[46] "where low and middle clouds are frequent, the ground observations of cirrus probably record but 50% of the true frequency". Therefore, the ground-based

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38. Fritz, S., and Rao, P.K. (1967) On the infrared transmission through cirrus clouds and the estimation of relative humidity from satellites, J. Appl. Meteorol. 6:1088-1096.
39. Kuhn, P.M., and Weickmann, H.K. (1969) High altitude radiometric measurements of cirrus, J. Appl. Meteorol. 8:147-154.
40. Davis, P.A. (1971) Applications of an airborne ruby lidar during a BOMEX program of cirrus observations, J. Appl. Meteorol. 10:1314-1323.
41. Platt, C.M.R. (1973) Lidar and radiometric observations of cirrus clouds, J. Atmos. Sci. 30:1191-1204.
42. Roewe, D., and Liou, K.-N. (1978) Influence of cirrus clouds on the infrared cooling rate in the troposphere and lower stratosphere, J. Appl. Meteorol. 17:92-106.
43. Derr, V.E. (1980) Attenuation of solar energy by high, thin clouds, Atmos. Environ. 14:719-729.
44. Platt, C.M.R., and Dilley, A.C. (1981) Remote sounding of high clouds. IV: Observed temperature variations in cirrus optical properties, J. Atmos. Sci. 38:1069-1082.
45. Chang, D.T., and Willand, J.H. (1972) Further Developments in Cloud Statistics for Computer Simulations, NASA CR-61389, N72-31615.
46. Stone, R.G. (1957) A Compendium on Cirrus and Cirrus Forecasting, Air Weather Service Technical Report, AWS-TR-105-130, AD A141546.

observer climatologies of Reference 45 were multiplied by 1.25 to give a more representative probability of cirrus present. In Table 6 the recommended cirrus climatologies for the tropics (inter-tropical convergence zone), temperate, and subarctic regions are presented.

Table 6. A Recommended Cirrus Climatology Based on Surface-based Observations, Compensated for Obscuration by Lower Clouds

Latitude zone	Tropics (ITCZ) 10°S - 20°N	Temperate or Midlatitude		Subarctic or Polar latitudes	
		Summer	Winter	Summer	Winter
Fraction of time cirrus clouds are present	0.80	0.40	0.50	0.45	0.40

Even though ground observations may show an apparent diurnal variation in the amount of cirrus coverage, this is most probably caused by the difficulty of observing cirrus during the nighttime hours. Therefore, we recommend following the conclusion of Stone[46] that, "there is probably no real diurnal variation in cirrus except where air mass thunderstorms or orographic effects are important". Also, the long lifetimes of cirrus, attributable to the slow evaporation of the typically large ice crystals, probably result in little diurnal variation.

7.3 Cirrus Height and Thickness Statistics

The distinguishing characteristic of cirrus and cirrostratus clouds, according to the International Cloud Atlas,[47] is that these clouds are "composed almost exclusively of ice crystals". Because of the usual scarcity of freezing nuclei active above -20°C in the atmosphere, cirrus clouds are not usually found at temperatures higher than this. Except in polar regions and in wintertime temperate zones near the Arctic or Antarctic, these low temperatures generally occur only in the middle or upper troposphere. Thus, cirrus are usually classed as high clouds, although by definition ice fogs (in German, "Diamantstaub") can also be called cirrus.

In the Compendium on Cirrus Forecasting by Stone,[46] cirrus thickness statistics measured by the British Meteorological Research flights and by the U.S. Air Force Project WIBACK are given. In addition, Weickmann[48] and Alt[49] present cirrus thickness measurements. When these various statistics are

References 47 to 49 will not be listed here. See References, page 151.

plotted on a graph of thickness vs the percentage of time that a given thickness occurs, a histogram as shown in Figure 19 results. This highly-skewed histogram shows a median cirrus thickness at 1.0 km. When the logarithms of the thicknesses shown in Figure 19 are plotted vs probability of occurrence, a straight line results, except for the most thin and thick extremum points. Cirrus thicknesses thus seem to occur in a truncated lognormal distribution. This is not unexpected since López[50, 51] has shown that other (convective) cloud properties are so distributed. Most of the moisture at cirrus levels must reach these heights through convective clouds. Cirrus with the thickness statistics shown in Figure 19 can occur throughout the middle and upper troposphere and occasionally into the lower stratosphere where the moisture may have reached such levels through breaks in the tropopause. In Table 7 the height ranges where cirrus may be expected are presented based on the average temperature profiles for the latitudes shown.

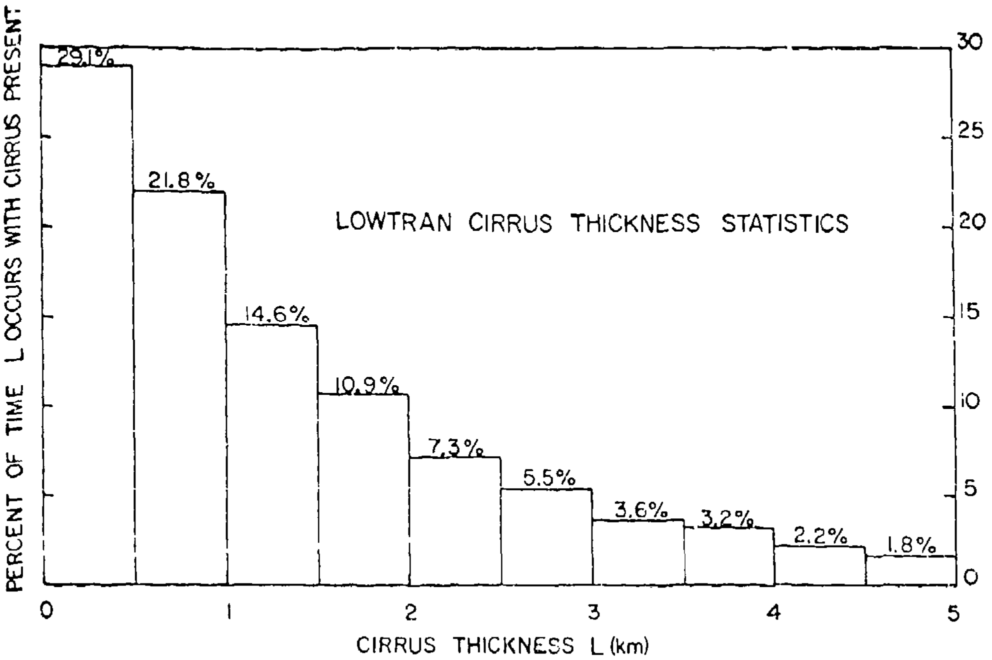

Figure 19. Histogram of Cirrus Thickness, Showing the Percentages of Time that Different Thicknesses (in 500-m Increments) are Found When Cirrus are Present. Median thickness is 1.0 km

50. López, R.E. (1977) The lognormal distribution and cumulus cloud populations, Mon. Wea. Rev. 105:865-872.

51. López, R.E. (1978) The determination of convective shower populations from radar data, Preprint, 18th Conf. Radar Meteorol., Amer. Meteorol. Soc., Boston, Mass., 155-158.

Table 7. Cirrus Height Ranges

Tropics	7.50 - 16.50 km
Temperate, winter	4.50 - 14.00 km
Temperate, summer	7.30 - 13.50 km
Polar, winter	2.50 - 10.00 km
Polar, summer	4.50 - 9.50 km

7.4 Cirrus Transmittance Models

A number of investigators have constructed transmittance models for water droplet clouds[52-56] and most of these calculations are based on extinction by Mie theory scattering and absorption in the spherical cloud droplets for known cloud droplet size distribution. Only Plass and Kattawar[53] considered ice clouds in their models. Their ice crystals were assumed to be spherical and the numbers and sizes of ice spheres used are not too realistic based on measurements that have since become available. Knowledge of actual cirrus ice-crystal size distributions has been greatly improved through a series of measurements made by the Air Force Geophysics Laboratory in the late 1970's.[57-60] Derr[43] has used these recent cirrus ice crystal sizes and number density information to model the transmission through cirrus, assuming ice spheres of equivalent

52. Deirmendjian, D. (1964) Scattering and polarization properties of water clouds and hazes in the visible and infrared, Appl. Opt. 3:187-196.

53. Plass, G.N., and Kattawar, G.W. (1971) Radiative transfer in water and ice clouds in the visible and infrared region, Appl. Opt. 10:738-748.

54. McClatchey, R.A., Fenn, R.W., Selby, J.E.A., Volz, F.E., and Garing, J.S. (1971) Optical Properties of the Atmosphere (Revised), AFCRL-71-0279, AD A726116.

55. Kuhn, P.M., Weickmann, H.K., Lojko, M.J., and Stearns, L.P. (1974) Transfer of infrared radiation through clouds, Appl. Opt. 13:512-517.

56. Manton, M.J. (1980) Computations of the effect of cloud properties on solar radiation, J. Recherches Atmospheriques, 14:1-16.

57. Varley, D.J. (1978) Cirrus Particle Distribution Study, Part 1, AFGL-TR-78-0192, AD A061485.

58. Varley, D.J., and Brooks, D.M. (1978) Cirrus Particle Distribution Study, Part 2, AFGL-TR-78-0248, AD A063807.

59. Varley, D.J. (1978) Cirrus Particle Distribution Study, Part 3, AFGL-TR-78-0305, AD A066975.

60. Varley, D.J., and Barnes, Jr., A.A. (1979) Cirrus Particle Distribution Study, Part 4, AFGL-TR-79-0134, AD A058982.

volume to the nonspherical particles. If the attenuation coefficient calculated by Derr is plotted vs the cirrus ice crystal number density, (particles per cubic meter), the plot of Figure 20 results. It is clear that for the realistic particle number densities and sizes for the clouds so modeled there appears to be no relationship between number density and attenuation coefficient. If, on the other hand, the attenuation coefficient is plotted vs the equivalent LWC for the cirrus, we obtain the rather linear plot of Figure 21. This same linear relationship between extinction and LWC has been found to hold in the infrared for liquid droplet clouds.[61-63] A number of the AFGL cirrus particle measurements give both cirrus LWC and cloud thickness.[57-60] When a plot is made of these two variables, the graph shown in Figure 22 results. It appears that LWC is directly proportional to cloud thickness and since the attenuation coefficient is also directly proportional to LWC, then the attenuation coefficient must be proportional to cloud thickness also.

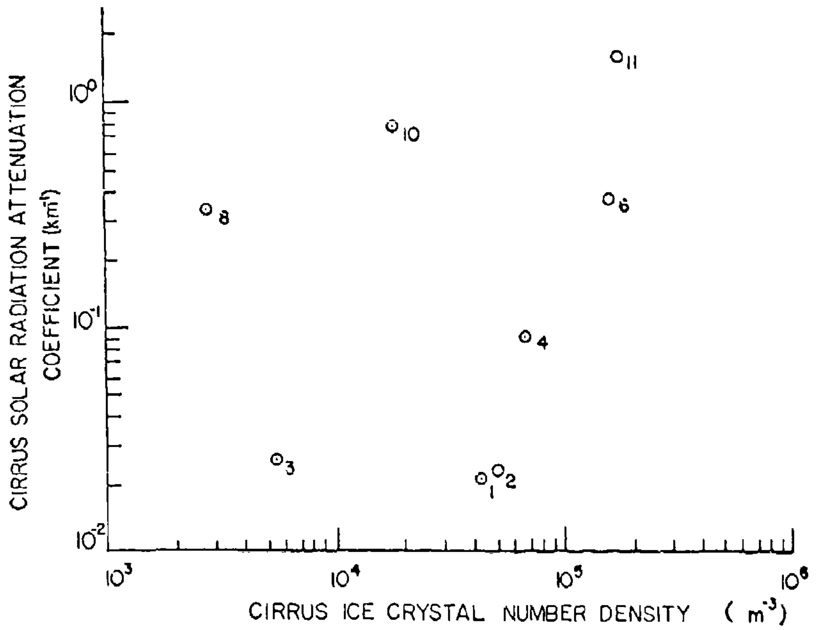

Figure 20. Calculated Cirrus Attenuation Coefficients for Solar Radiation Plotted vs Ice Crystal Number Density. The numbers on the data points refer to model numbers used by Derr

References 61 to 63 will not be listed here. See References, page 151.

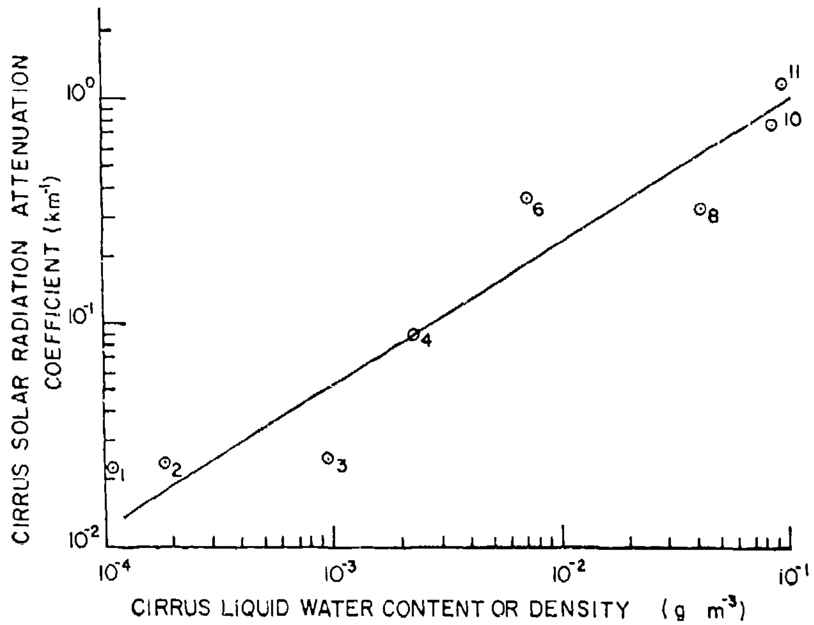

Figure 21. Calculated Cirrus Attenuation Coefficients for Solar Radiation Plotted vs Cloud Liquid Water Content (LWC). Again, the numbers are the cirrus model numbers used by Derr

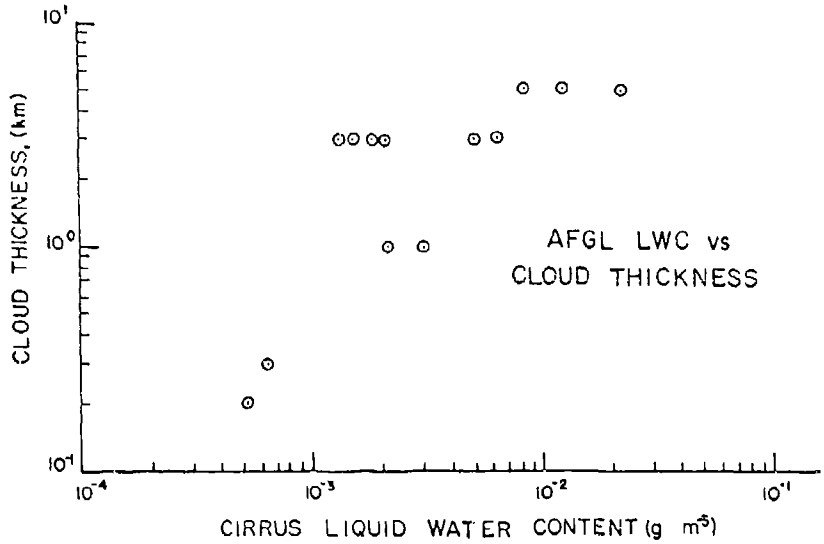

Figure 22. Cirrus Cloud Thickness vs Liquid Water Content (LWC) From AFGL Measurements

7.5 Cirrus Transmittance and Thickness Data

As part of a Department of Energy study, NOAA investigated the transmittance of all cloud types using a nine-channel, filtered photometer/radiometer and a pulsed ruby lidar to measure cloud height and thickness.[64] Data were obtained at Erie and Grover, Colorado; White Sands Missile Range, New Mexico; Colstrip, Montana, and later at Point Mugu, California. Time lapse, all-sky camera coverage allowed choosing cases when cirrus clouds alone contributed to solar radiation attenuation. It was necessary to use the camera because the lidar pointed vertically to monitor cloud height and thickness, but the photometer/radiometer tracked the sun. Forty independent cases were selected for analysis and these cases were chosen for clouds with trajectories that passed through the zenith, then eclipsed the sun, or for clouds that eclipsed the sun and then passed through the zenith. Of course it was impossible to determine that the exact same portion of the advecting cirrus clouds affected the photometer and lidar with perfect time-lagged spatial correlation. Cirrus are notorious for large variations of transparency even when extensive cirrostratus sheets are encountered. This variability led Valovcin[65] to despair of ever obtaining a cirrus transmittance model. Nonetheless, when the attenuation coefficient calculated for the measured cirrus thickness (using the photometer channel at 0.975 μm) was plotted vs the cloud thickness for the forty cases, we obtained the plot of Figure 23. For cases where cloud thickness was not rapidly varying with time, single circles are plotted. For cases where scattered cirrus, that seemed to be fibrous and covering the entire sky but could not be sampled through the same portion of the cloud with the lidar and photometers, X's are plotted. For cases when multiple layers were measured with the lidar, the number of significant layers so measured is indicated by the number above the line connecting the two extremes in thickness of the clouds for the several minutes when that same portion of the cloud eclipsed the photometer. Although there is significant scatter to the data, the straight line shown on Figure 23 represents the best experimental fit to the forty case data set.

For most of the thinner clouds with total optical thickness (attenuation coefficient multiplied times the cloud thickness), less than 0.5, very little spectral dependence could be found over the entire range examined, 0.317 μm to the 8 through 12 μm window region. For the thicker clouds, the optical thickness seemed to increase at the longer wavelengths, but this could well have been an

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64. Lerfald, G.M., Derr, V.E., Abshire, N.L., Cupp, R.E., and Ericson, H.L. (1980) Optical properties of clouds and aerosols derived from ground-based remote sensing methods, Role of Electro-Optics in Photovoltaic Energy Conversion, SPIE vol. 248, 166-171.

65. Valovcin, F.R. (1968) Infrared measurements of jet-stream cirrus, J. Appl. Meteorol. 7:817-826.

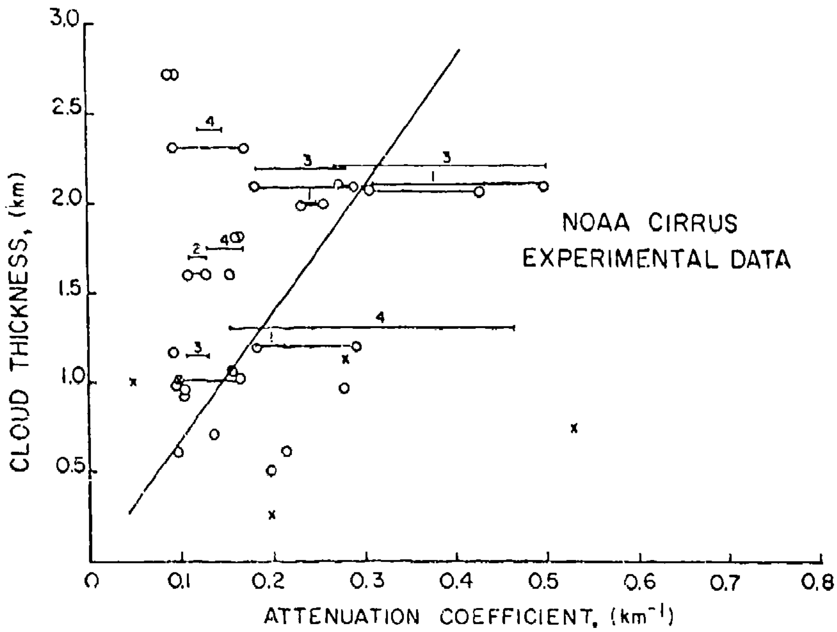

Figure 23. NOAA Measurements of Cirrus Transmittance. Solar irradiance was measured using a nine-channel photometer/radiometer and cloud thickness with a pulsed ruby lidar

artifact of the larger field-of-view of the short wavelength photometer. The smaller field-of-view of the infrared radiometer did not sample as much forward scattered radiation and, of course, the smaller effective size parameter at the infrared wavelengths would lead to a wider scattering diagram. Our best estimate is that the attenuation coefficient for cirrus is independent of the wavelength over the range measured during our study, or 0.317 to 10 μm.

7.6 An Analytical Model of Cirrus Transmittance

The best fit to the experimental data shown on Figure 23 is expressed by the relationship, $k = 0.14\ L$, where the attenuation coefficient, k, is in the units per kilometer and the cloud thickness, L, is measured in kilometers. When the experimental data is plotted on the same graph as the AFGL LWC model based on Derr's calculations, the graph of Figure 24 results. It is seen that the LWC model leads to a slightly lower attenuation coefficient for most cirrus clouds. Because of the uncertainties in the model, especially the assumption of the equivalent size spheres, it is felt that the experimental data should be used. It is encouraging, however, to see that the model and experimental data agree rather closely in spite of the many assumptions in the model and the difficulty in

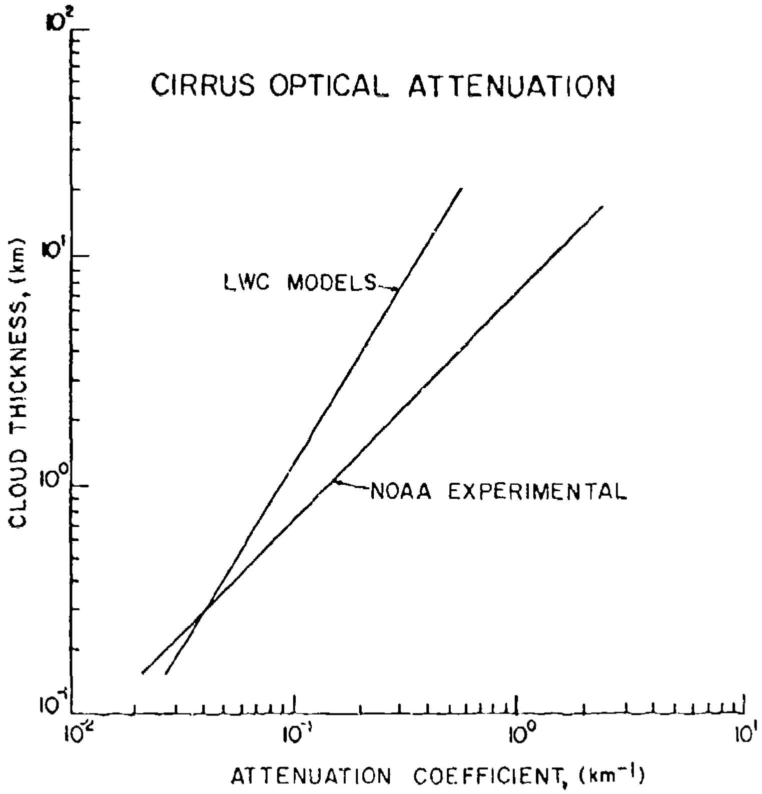

Figure 24. A Comparison of the NOAA Experimental and AFGL Liquid Water Content (LWC) Calculated Attenuation Coefficient for Cirrus. The experimental data curve is chosen for the LOWTRAN model, as explained in the text

making the measurements that lead to the experimental curve. We thus have an equation for cirrus normal transmittance, τ, of the form

$$\tau = \exp - (0.14\ L^2) \quad . \tag{49}$$

This expression closely duplicates the double exponential model of Davis[40] for most realistic cirrus thicknesses. Even though a constant attenuation coefficient $k = 0.2\ \mathrm{km}^{-1}$ is nearly as good a fit to the experimental data, the LWC dependence on cloud thickness argues in favor of the adopted expression.

7.7 Cirrus Computer Subroutine

A cirrus subroutine (CIRRUS) was added to the LOWTRAN 6 code to include the extinction due to cirrus clouds. As indicated in the user instructions in Section 10, the cirrus subroutine is called by setting ICIR = 1 on CARD 2. The default value for the cirrus thickness is the median value of 1 km and for the cirrus base altitude is 11, 10, 8, 7, and 5 km for the tropical, midlatitude summer, midlatitude winter, subarctic summer, and subarctic winter models respectively. The user may override the default values by specifying CTHIK (cirrus thickness) and CALT (cirrus base altitude).

If the user sets the random number initialization flag ISEED $\neq 0$, the program will generate random cirrus thicknesses according to the probability distribution shown in Figure 19. (The appropriate computer system random number generator must be included.) This feature may be of use in electro-optical systems studies to establish transmittance probability statistics. To use this option, the program must be run repeatedly using the control parameter IRPT > 0 on CARD 4.

8. RAIN MODEL

8.1 Introduction

In developing a rain model to be used in the LOWTRAN code the first consideration was relating the transmission over a given path to the most directly obtainable meteorological parameter. This parameter is the rain rate in mm/h, reported by worldwide weather stations on a six hourly basis.

The Marshall-Palmer (M-P)[66] raindrop size distribution was chosen because the two main components are rain rate and drop diameter, and the M-P raindrop size distribution is widely accepted in the research community. The M-P distribution is the same one being used in the millimeter region (Falcone et al)[67] by the FASCODE (Clough et al)[9] high-resolution atmospheric transmittance/radiance modeling code.

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66. Marshall, J.S., and Palmer, W.M.K. (1948) The distribution of raindrops with size, J. Meteorol. 5:165-166.

67. Falcone, Jr., V.J., Abreu, L.W., and Shettle, E.P. (1979) Atmospheric Attenuation of Millimeter and Submillimeter Waves: Models and Computer Code, AFGL-TR-79-0253, AD A084485.

8.2 Formulation of the Model

The M-P dropsize distribution is given in Eq. (50).

$$\frac{dN}{dD} = n\,(D) = N_o \exp\,(-\Lambda D) \quad , \tag{50}$$

where

$$N_o = 8{,}000.\ \mathrm{mm}^{-1}\,\mathrm{m}^{-3} \tag{51a}$$

$$\Lambda = 4.1\,R^{-0.21} \tag{51b}$$

R = rain rate ($\mathrm{mm\ hr}^{-1}$)

D = drop diameter (mm) .

From Mie theory we can write the extinction coefficient, k_{ext}:

$$k_{ext} = \int_0^{\infty} \frac{\pi}{4} D^2\, Q_{ext}\,[\pi D/\lambda,\ m(\lambda)]\, \frac{dN}{dD}\, dD \quad , \tag{52}$$

where Q_{ext} is the Mie Extinction Efficiency, λ is the wavelength, and $m(\lambda)$ is the complex refractive index of water. Since for rain $0.1 < D < 5$ mm, in the visible and infrared we have $(D >> \lambda)$. Therefore, $Q_{ext} \approx 2$, independent of the wavelength. Using this assumption and Eq. (50) in Eq. (52) we have:

$$k_{ext} \approx \frac{\pi}{2} N_o \int_0^{\infty} D^2 \exp(-\Lambda D)\, dD \quad . \tag{53}$$

Carrying out the integration, this simplifies to:

$$k_{ext} \approx \pi N_o \Lambda^{-3} \quad . \tag{54}$$

Substituting Eq. (51) in Eq. (54) yields:

$$k_{ext} \approx 0.365\, R^{0.63}\ (\mathrm{km}^{-1}) \quad . \tag{55}$$

We should note here that this derivation shows that the extinction due to rain is independent of wavelength, assuming

$$\lambda << D \approx 0.1 \text{ to } 10 \text{ mm} \quad .$$

In practice this assumption applies throughout the visible and the IR windows.

The transmittance over path length, s, in km, can be written as

$$\tau = \exp(-ks) \quad , \tag{56}$$

or using Eq. (55)

$$\tau = \exp(-0.365\, R^{0.63}\, s) \quad . \tag{57}$$

It should be recognized that the extinction [Eq. (55)] or transmittance [Eq. (57)] measured by a transmissometer will, in general, have to be corrected for forward scattering effects. However, since this correction is a function of the receiver and source geometries it is beyond the scope of the current LOWTRAN model. A discussion of this correction is given by Shettle et al.[68]

8.3 Other Raindrop-Size Distribution Formulations

Several researchers have attempted to relate the parameters in the exponential rain dropsize distribution to the type of rainfall (for example, Joss and Waldvogel,[69] and Sekhon and Srivastava[70]). These different parameterizations lead to an expression similar to Eq. (55) for the extinction:

$$k_{ext} = A \cdot R^B \quad . \tag{58}$$

For the convenience of the LOWTRAN users who may wish to modify SUBROUTINE TNRAIN, to implement one of these other models, the parameters for size distributions and extinction coefficients are summarized in Table 8.

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68. Shettle, E.P., Fenn, R.W., and Mill, J.D. (1983) The Optical and Infrared Properties of Atmospheric Particulates, AFGL-TR-83- (to be published).

69. Joss, J., and Waldvogel, A. (1969) Raindrop size distributions and sampling size errors, J. Atmos. Sci. 26:566-569.

70. Sekhon, R.S., and Srivastava, R.C. (1971) Doppler radar observations of drop-size distributions in a thunderstorm, J. Atmos. Sci. 28:983-984.

Table 8. Parameters Relating Size Distribution [Eq. (50)] Extinction Coefficient [Eq. (58)] to Rain Rate for Different Types of Rain

Type of Rain	N_o (mm^{-1} m^{-3})	Λ (mm^{-1})	A	B
Marshall-Palmer[66]	8,000	$4.1\ R^{-0.21}$	0.365	0.63
Drizzle (Joss and Waldvogel)[69]	30,000	$5.7\ R^{-0.21}$	0.509	0.63
Widespread (Joss and Waldvogel)[69]	7,000	$4.1\ R^{-0.21}$	0.319	0.63
Thunderstorm (Joss and Waldvogel)[69]	1,400	$3.0\ R^{-0.21}$	0.163	0.63
Thunderstorm (Sekhon and Srivastava)[70]	$7{,}000\ R^{0.37}$	$3.8\ R^{-0.14}$	0.401	0.79

The divergence between the two different thunderstorm models indicates the difficulty in making such parameterizations and the uncertainty in the parameter values given.

8.4 Sample Output of Typical Rain Cases

The atmospheric transmittance, using the M-P model with the LOWTRAN code for rain rates varying from 1 to 100 mm/hr is shown in Figure 25 for 400 through 4000 cm^{-1} and in Figure 26 for 4000 through 40000 cm^{-1}.

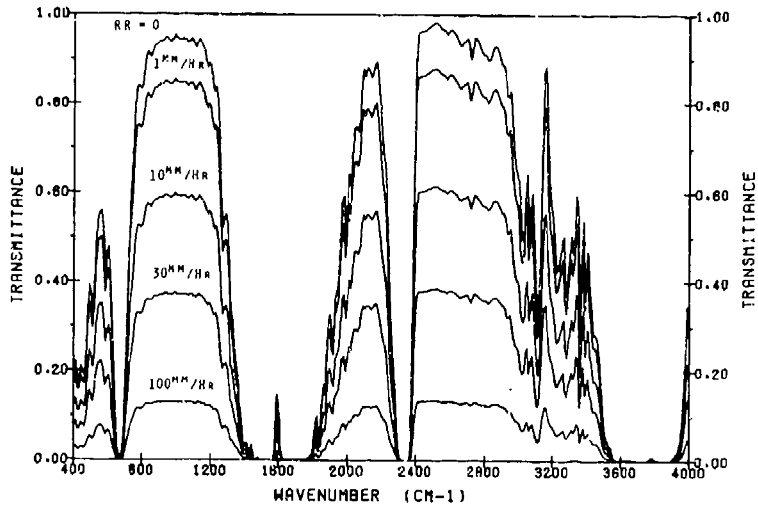

Figure 25. Atmospheric Transmittance for Different Rainrates (RR) and for Frequencies From 400 to 4000 cm^{-1}. The measurement path is 300 m at the surface with $T = T_{dew} = 10^{o}C$, with a meteorological range of 23 km in the absence of rain

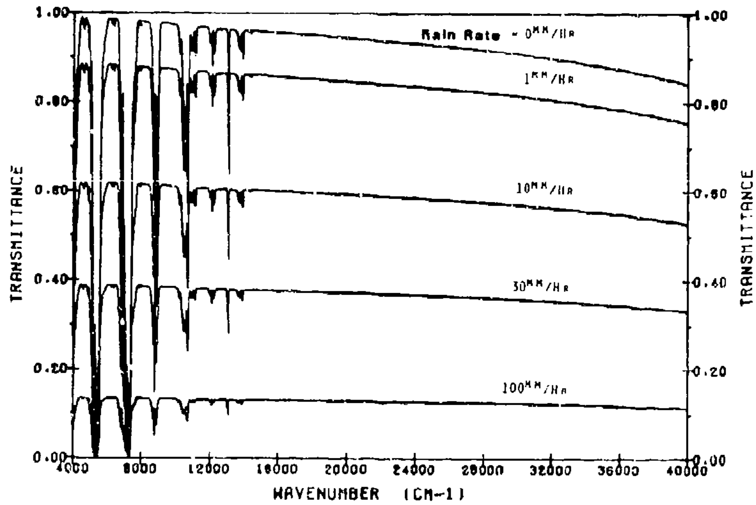

Figure 26. Atmospheric Transmittance for Different Rainrates (RR) and for Frequencies From 4000 to 40000 cm^{-1}. The measurement path is 300 m at the surface with $T = T_{dew} = 10^{o}C$, with a meteorological range of 23 km in the absence of rain

9. DISCUSSION OF LOWTRAN 6 CODE

This section describes the LOWTRAN 6 program structure, including the structure of several modules of subroutines. Five tables are presented that include names and descriptions of each subroutine as they appear in the program.

Section 9.2 discusses program portability, Fortran compatibility, precision, and some specific comments relating to implementing the program. Specific instructions are given in Section 9.3 enabling the user to reduce the execution field length. Lastly, the availability of the program package is detailed in Section 9.4.

9.1 LOWTRAN 6 Code Structure

A graphical representation of the LOWTRAN 6 main program structure is depicted in Figure 27. The structure for non-standard model, air mass, single scattering geometry, and transmittance modules are shown in Figures 28 through 31 respectively. Descriptions of the major executable subroutines shown in Figure 27 are given in Table 9. The subroutines in the air mass, single scattering geometry, and transmittance modules are explained in Tables 10, 11, and 12 respectively. Table 13 contains a brief description of the Block Data subroutines.

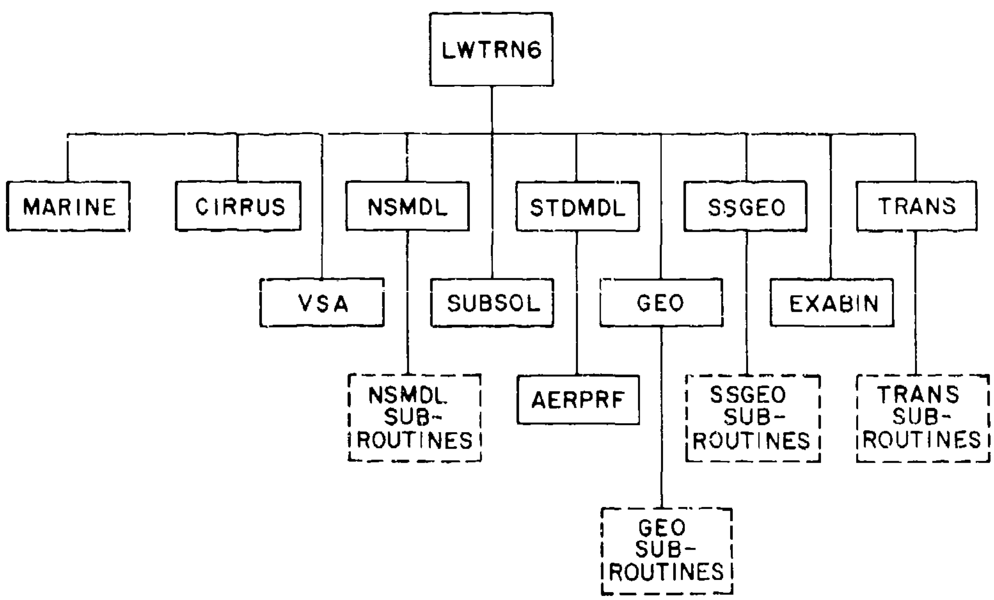

Figure 27. LOWTRAN 6 Main Program Structure. The boxes enclosed by dashes are modules of subroutines for the calculation of non-standard models, air mass geometry, single scattering geometry, and transmittance

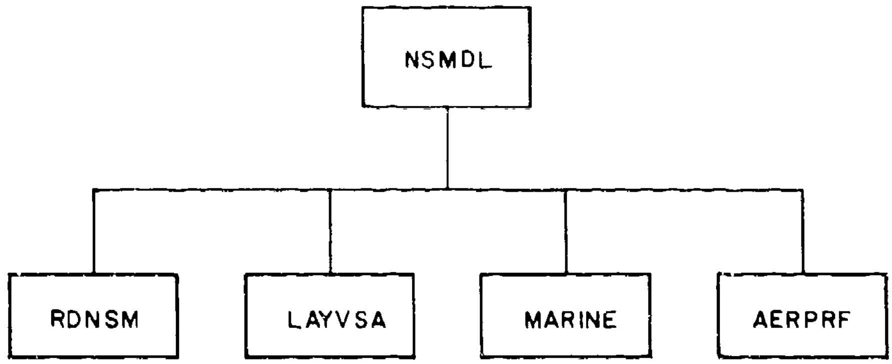

Figure 28. Program Structure for the Non-standard Model Subroutines

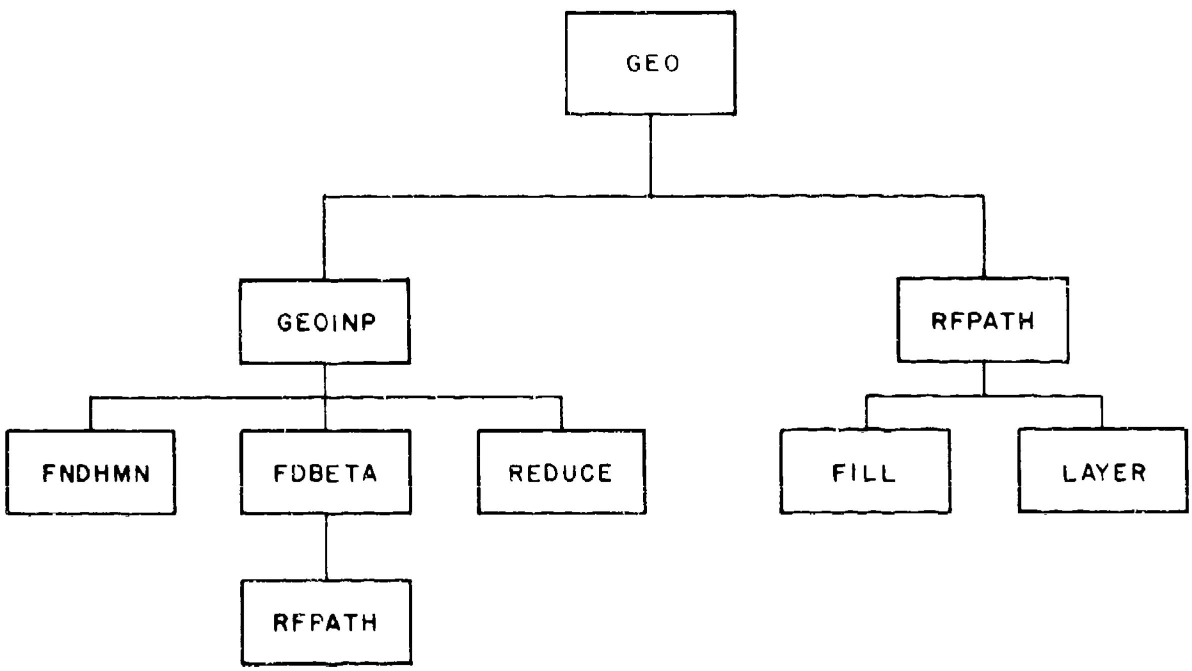

Figure 29. Program Structure for the Air Mass Geometry Subroutines

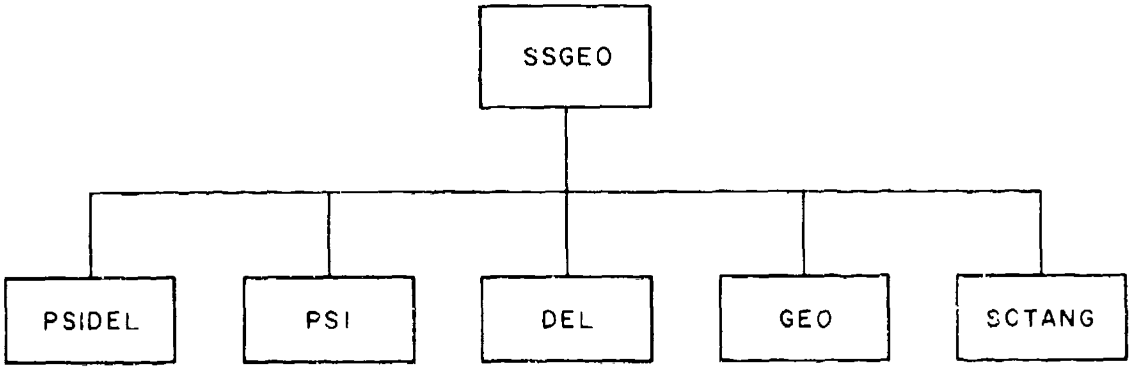

Figure 30. Program Structure for the Single Scattering Geometry Subroutines

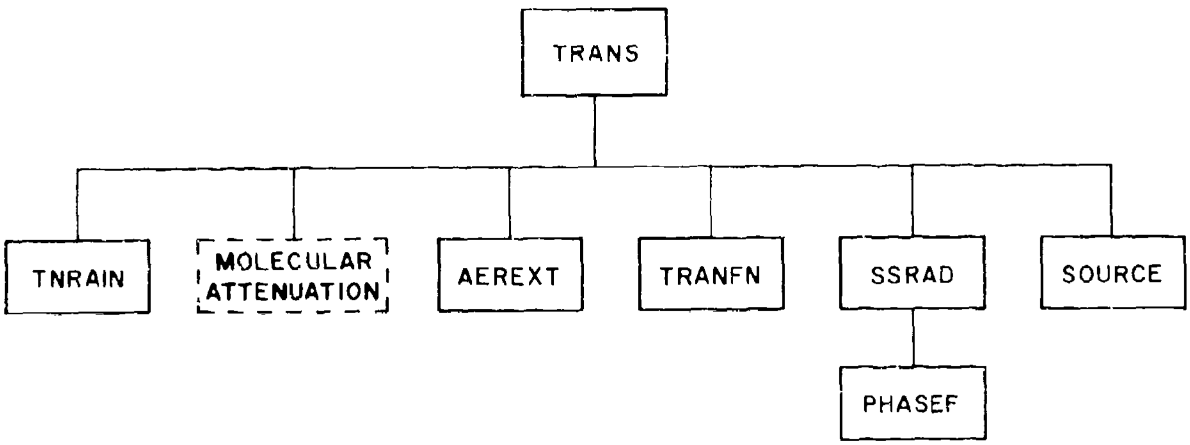

Figure 31. Program Structure for the Transmittance Subroutines. The dashed box labelled Molecular Attenuation includes the following subroutines: C1DTA, C2DTA, C3DTA, C4DTA, C6DTA, SLF296, SLF260, FRN296, and HNO3

Table 9. Description of LWTRN6 Subroutines

LWTRN6	- Main driver program. Reads control cards.
MARINE	- Determines aerosol extinction and absorption coefficients for the Navy maritime model.
CIRRUS	- Generates altitude profiles of cirrus cloud density.
RANDOM	- Calls machine-dependent function RANF, that is a uniform random number generator.
VSA	- Army vertical structure algorithm of aerosol extinction and relative humidity for low visibility/ low ceiling conditions.
NSMDL	- For user-defined atmospheric or aerosol profiles.
LAYVSA	- Restructures the atmospheric profile for finer layering near the ground for use with the VSA option.
RDNSM	- Reads model 7 data for Army vertical structure algorithm.
SUBSOL	- Calculates the subsolar point angles based upon time and day.
STDMDL	- Sets up atmospheric profiles of attenuator densities.
AERPRF	- Computes scaling factor profiles for aerosols.
GEO	- Driver for air mass subroutines. Calculates attenuator amounts for the slant path.
SSGEO	- Obtains attenuator amounts from scattering points along optical path to the extraterrestrial source.
EXABIN	- Loads aerosol extinction and absorption coefficients for the appropriate model and relative humidity.
TRANS	- Calculates transmittance, atmospheric radiance, and solar/lunar scattered radiance for slant path.

Table 10. Description of Air Mass Subroutines

GEO	- Driver for air mass subroutines. Calculates attenuator amounts for the slant path.
GEOINP	- Interprets geometry input parameters into the standard form H1, H2, ANGLE, and LEN.
FNDHMN	- Calculates HMIN, the minimum altitude along the path and PHI, the zenith angle at H2.
REDUCE	- Eliminates slant path segments that extend beyond the highest profile altitude.
FDBETA	- Calculates angle, given H1, H2, and BETA by iteration.
RFPATH	- Determines the refracted path and the absorber amounts through all the layers.
FILL	- Defines the boundaries of the slant path and interpolates densities at these boundaries.
LAYER	- Calculates the path and amounts through one layer.
RADREF	- Computes radius of curvature of the refracted ray for a horizontal path.
FINDSH	- Finds layer boundaries and scale height at ground for index of refraction.
SCALHT	- Calculates scale height of index of refraction.
ANDEX	- Computes index of refraction at a specific height.
EXPINT	- Performs exponential interpolations for the geometry routines.

Table 11. Description of SSGEO Subroutines

SSGEO	- Obtains attenuator amounts from scattering points along optical path to the extraterrestrial source.
PSIDEL	- Calculates the relative azimuth between the line of sight and the direct solar/lunar path.
PSI	- Returns solar azimuth relative to line-of-sight at current scattering location.
DEL	- Returns solar zenith angle at any point along optical path.
GEO	- Driver for air mass subroutines. Calculates attenuator amounts for the slant path.
SCTANG	- Returns the scattering angle at any point along the optical path.

9.2 Portability

LOWTRAN 6 was developed on a CDC 6600 (a 60 bit-per-word machine) with the FORTRAN 77 (FORTRAN 5) compiler. A major effort has been made to make LOWTRAN 6 as compatible as possible with both ANSI standard FORTRAN 66 (FORTRAN 4) and 77, and to run in single precision on a 32 bit-per-word computer. For the most part, this goal has been achieved. The only non-ANSI FORTRAN 77 feature is that type CHARACTER is not used, rather character data is stored as Hollerith data in real variables, four characters per word. This feature is compatible with FORTRAN 66 and most FORTRAN 77 compilers allow it as well. For FORTRAN 66 compilers, three non-ANSI features used are the OPEN statements, named BLOCK DATA, and single quotes in FORMAT statements. It should be a very simple matter to modify the appropriate statements.

LOWTRAN 6 uses three files:

1. INPUT, read on UNIT = 5, containing LOWTRAN input directions. Maximum record length is 80 characters.

2. OUTPUT, written on UNIT = 6, containing the standard LOWTRAN output. Maximum record length is 120 characters.

3. TAPE7, written on UNIT = 7, containing copies of the input cards and the spectral results (transmittance and/or radiance). Maximum record length is 120 characters.

The unit numbers for these files are stored in the variables IRD(=5), IPR(=6), and IPU(=7), which are carried in the common block IFIL. These files are accessed using OPEN statements in the main program.

Table 12. Description of TRANS Subroutines

TRANS	- Calculates transmittance, atmospheric radiance, and solar/lunar scattered radiance for slant path.
AEREXT	- Interpolates aerosol attenuation coefficients to required wavenumber.
HNO3	- Determines nitric acid absorption coefficient at required wavenumber.
TRANFN	- Calculates transmittance for ozone, uniformly-mixed gases, and water vapor.
SOURCE	- Contains solar intensity data and calculates lunar intensity.
TNRAIN	- Calculates transmittance of rain as a function of rain rate and slant range.
SSRAD	- Performs the layer by layer single scattering radiance sum.
PHASEF	- Chooses correct phase function based on relative humidity, frequency, scattering angle, and model.
INTERP	- Performs linear or logarithmic interpolation.
PF	- Returns the appropriate phase function from the stored database.
C1DTA	- Returns water vapor band absorption coefficient at required wavenumber.
C2DTA	- Returns uniformly-mixed gases absorption coefficient at required wavenumber.
C3DTA	- Returns ozone band absorption coefficient at required wavenumber.
C4DTA	- Returns N_2 continuum absorption coefficient at required wavenumber.
C6DTA	- Returns molecular scattering attenuation coefficient at required wavenumber.
C8DTA	- Returns ozone UV and visible absorption coefficient at required wavenumber.
SLF296	- Loads self-broadened water vapor continuum at $296^{\circ}K$.
SLF260	- Loads self-broadened water vapor continuum at $260^{\circ}K$.
FRN296	- Loads foreign-broadened water vapor continuum at $296^{\circ}K$.
SINT	- Performs interpolation for water vapor continuum.

Table 13. Description of Block Data Subroutines

MDTA	- Model atmospheric data.
TITLE	- Titles for outputs.
PRFDTA	- Aerosol profile data.
EXTDTA	- Aerosol extinction and absorption data.
SF296	- Self-broadened absorption coefficients for water vapor continuum at 296°K.
SF260	- Self-broadened absorption coefficients for water vapor continuum at 260°K.
BFH20	- Foreign-broadened absorption coefficients for water vapor continuum at 296°K.
TRFN	- LOWTRAN transmittance functions.
C1D	- Water vapor band model absorption coefficients.
C2D	- Uniformly-mixed gases band model absorption coefficients.
C3D	- Ozone band model absorption coefficients.
C4D	- Nitrogen continuum absorption coefficients and UV ozone absorption coefficients.
MARDTA	- Navy marine aerosol extinction and absorption data.
PHSDTA	- 70 Averaged phase functions and truth table identifying correct phase function.

For computers with virtual memory, the program must be compiled with "GLOBAL SAVE" or the local equivalent. Otherwise, information relating to the phase function is initialized in a first call to a subroutine, but lost in subsequent calls.

The cirrus cloud model includes an option to generate cirrus clouds at random altitudes. This option calls the random number generator function subroutine RANF, which is called from RANDOM. The user will have to supply the local equivalent of RANF.

The user may find it useful to have the date and time printed at the beginning of each case. The statements required to do this are commented out in the main program with 'C@' in columns 1 and 2. The subroutines FDATE and FCLOCK, which return the date and time in A8 format, are commented and located at the

end of the main program LWTRN 6. The user will have to modify these subroutines as necessary.

The sample output included on the LOWTRAN 6 tape was generated on a CDC 6600 that has 14 decimal digits of precision. The output for these same cases generated in a 32 bit-per-word machine with about seven decimal digits of precision (for example, an IBM 370 or 4341 or a VAX) should agree with the sample to within about four decimal digits. This precision is better than the accuracy of the models, so that going to DOUBLE PRECISION to increase the precision would produce no real benefit. When calculating the radiance where the whole path is at high altitude (40 km or more), the truncation error of a 32 bit-per-word machine might cause the emission to be zero.

When run on an IBM 370 or 4341 using the FORTRAN G compiler, sample case 5 (Section 11) generates two boundaries, both at 1.8 km, and then produces divide checks in subroutine LAYER. However, the final answers agree with the sample output found in this report. We have not found a solution to this problem.

9.3 Execution Field Length

On a CDC 6600, LOWTRAN 6 requires 136000_8 of core memory to run (144000_8 to load). There are several techniques available to the user to reduce the executable field length if desired. On CDC CYBER systems, the program may be run using the SEGMENT loader, which effectively creates an overlay structure. File 2 of the LOWTRAN 6 tape (Section 9.4) gives the SEGMENT loader directives that reduce the field length to less than 75000_8. Users of other systems who wish to create overlays should consult the structure chart in Figure 27 and the SEGMENT input directives for guidance. If certain program options are not required, the field length can also be reduced by not including the corresponding subroutines. For example, if the Solar Scattering option is not required the subroutines SSGEO, PSIDEL, PSI, DEL, SCTANG, SUBSOL, SSRAD, PHASEF, INTERP, PF, SOURCE, and PHSDTA and the common blocks SOLS and MNMPHS can be deleted saving about 17000_8 of field length.

9.4 Availability

The LOWTRAN 6 package is available from:

National Climatic Center, NOAA
Environmental Data Services
Federal Building
Asheville, NC 28801
(704) 258-2850, ext. 682 (Ms. Yolanda Goodge)

The package is normally distributed on magnetic tape with the following characteristics:

1. 9 track, 1600 BPI
2. unlabeled
3. ASCII
4. fixed-length records, 140 characters-per-record, one record per block.

The tape has 12 files. The contents of these files are as follows:

1. LOWTRAN 6 source code
2. SEGMENT input direction (relevant to CDC/NOS/BE systems only)
3. INPUT file for test cases
4. OUTPUT file for test cases
5. TAPE7 file for test cases
6. Source code for plot program (see Appendix A)
7. INPUT file for test cases of plot program
8. OUTPUT file for test cases of plot program
9. Source code for filter program (see Appendix B)
10. INPUT file for test cases of filter program
11. OUTPUT file for test cases of filter program
12. List of all LOWTRAN phase functions.

The record length for all the files is 140 characters; however, for files containing source code, INPUT files, and the phase functions, only the first 80 characters contain information. Users who require a different format should contact the National Climatic Center. The tape presently costs $99.00.

10. INSTRUCTIONS FOR USING LOWTRAN 6

The instructions for using LOWTRAN 6 are similar to those for previous versions. However, many new parameters have been added necessitating the addition of a fifth control card. The new parameters are principally required for the Navy maritime model, Army Vertical Structure Algorithm (VSA), NOAA Cirrus Cloud model, and inclusion of the Solar/Lunar Single Scattering model.

In general, for standard atmospheric models, five input cards are required to run the program for a given problem. For a specific problem utilizing any of the aforementioned algorithms, a combination of several of the ten additional optional control cards are possible. The formats for the five main cards, ten optional cards, and definitions of the input parameters are given below.

10.1 Input Data and Formats

The data necessary to specify a given problem are given on the input cards as follows:

```
CARD 1  MODEL, ITYPE, IEMSCT, M1, M2, M3, IM, NOPRT, TBOUND, SALB
          FORMAT(8I5,2F10.3)

CARD 2  IHAZE, ISEASN, IVULCN, ICSTL, ICIR, IVSA, VIS, WSS, WHH, RAINRT
          FORMAT(6I5,4F10.3)

        CARD 2A   CTHIK, CALT, ISEED              (ICIR = 1)
                    FORMAT(2F10.3,I10)

        CARD 2B   ZCVSA, ZTVSA, ZINVSA            (IVSA = 1)
                    FORMAT(3F10.3)

        CARD 2C1  ML, TITLE                       (MODEL = 7)
                    FORMAT(I5, 18A4)              (IM = 1)

        CARD 2C2(ML Cards)  Z, P, T, DP, RH, WH, WO, AHAZE, VIS1,
                            IHA1, ISEA1, IVUL1
                              FORMAT(3F10.3,2F5.1,3E10.3,F7.3,3I1)

        CARD 2D(10 Cards)   (DUMMY, EXTC(1,I), ABSC(1,I), I=1,40)
                            (IHAZE = 7)
                              FORMAT (4(F6.2,2F7.5))

CARD 3  H1, H2, ANGLE, RANGE, BETA, RO, LEN
          FORMAT(6F10.3,I5)

        ALTERNATE CARD 3  (MODEL = 0, ITYPE = 1)

        CARD 3    H1, P, T, DP, RH, WH, WO, RANGE
                    FORMAT(3F10.3,2F5.1,2E10.3,F10.3)

        CARD 3A1  IPARM, IPH, IDAY, ISOURC        (IEMSCT = 2)
                    FORMAT(4I5)

        CARD 3A2  PARM1, PARM2, PARM3, PARM4, TIME, PSIPO, ANGLEM,G
                  (IEMSCT = 2)
                    FORMAT(8F10.3)

        CARD 3B1  NANGLS                          (IPH = 1)
                    FORMAT(I5)

        CARD 3B2  (1 TO NANGLS)                   (IPH = 1)
                  (ANGF(I), F(1,I), F(2,I), F(3,I), F(4,I), I=1,NANGLS)
                    FORMAT(F10.3,4E10.3)

CARD 4  V1, V2, DV
          FORMAT(3F10.3)

CARD 5  IRPT
          FORMAT(I5)
```

Definitions of these quantities will be discussed in Section 10.2.

10.2 Basic Instructions

The various quantities to be specified on each of the five control cards along with the ten possible optional cards (summarized in Section 10. 1) will be discussed in this section.

10.2.1 CARD 1 MODEL, ITYPE, IEMSCT, M1, M2, M3, IM, NOPRT, TBOUND, SALB

The parameter MODEL selects one of six geographical model atmospheres or specifies that user-defined meteorological data are to be used in place of the standard models. ITYPE defines one of three types of atmospheric paths for a given problem. IEMSCT selects the mode of program execution (transmittance, radiance, or radiance with solar/lunar scattering). M1, M2, M3, IM, SALB, and TBOUND are additional input parameters for non-standard cases. NOPRT is a user option to suppress printing of profiles and tables in the output.

MODEL = 0 if meteorological data are specified (for horizontal paths only).
= 1 selects TROPICAL MODEL ATMOSPHERE.
= 2 selects MIDLATITUDE SUMMER.
= 3 selects MIDLATITUDE WINTER.
= 4 selects SUBARCTIC SUMMER.
= 5 selects SUBARCTIC WINTER.
= 6 selects 1962 U.S. STANDARD.
= 7 if a new model atmosphere (or radiosonde data) is to be inserted.

ITYPE indicates the type of atmospheric path.

ITYPE = 1 for a horizontal (constant-pressure) path.
= 2 for a vertical or slant path between two altitudes.
= 3 for a vertical or slant path to space.

IEMSCT determines the mode of execution of the program.

IEMSCT = 0 program calculates transmittance.
= 1 program calculates atmospheric radiance.
= 2 program calculates atmospheric and single scattered solar/lunar radiance.
= 3 program calculates directly transmitted solar irradiance.

M1, M2, and M3 are used to modify or supplement the altitude profiles of temperature and pressure, water vapor, and ozone respectively.

M1 = M2 = M3 = 0 for normal operation of program.

M1 = 1 selects the TROPICAL temperature and pressure altitude profiles.

= 2 selects the MIDLATITUDE SUMMER temperature and pressure altitude profiles.

= 6 selects the 1962 U.S. STANDARD temperature and pressure altitude profiles.

M2 = 1 selects the TROPICAL water vapor altitude profile.

= 2 selects the MIDLATITUDE SUMMER water vapor altitude profile.

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.

= 6 selects the 1962 U.S. STANDARD water vapor altitude profile.

M3 = 1 selects the TROPICAL ozone altitude profile.

= 2 selects the MIDLATITUDE SUMMER ozone altitude profile.

.

.

= 6 selects the 1962 U.S. STANDARD ozone altitude profile.

IM = 0 for normal operation of program or when subsequent calculations are to be run with MODEL = 7.

= 1 when radiosonde data are to be read in initially.

NOPRT = 0 for normal operation of program.

= 1 to suppress printing of the atmospheric profiles and the ray trace output.

TBOUND = boundary temperature (^{o}K), used in the radiance mode (IEMSCT = 1 or 2) for slant paths that intersect the earth or terminate at a grey boundary (for example cloud, target). If TBOUND is left blank and the path intersects the earth, the program will use the temperature of the first atmospheric level as the boundary temperature.

SALB = surface albedo of the earth at the location and average frequency of the calculation (0.0 to 1.0). If SALB is left blank, the program assumes the surface is a blackbody.

Table 14 summarizes the use of the four control parameters MODEL, ITYPE, IEMSCT, and NOPRT on CARD 1.

10.2.2 CARD 2 IHAZE, ISEASN, IVULCN, ICSTL, ICIR, IVSA, VIS, WSS, WHH, RAINRT

IHAZE, ISEASN, IVULCN, and VIS select the altitude- and seasonal-dependent aerosol profiles and aerosol extinction coefficients. IHAZE specifies the aerosol model used for the boundary-layer (0 to 2 km) and a default-surface meteorological range. The relative humidity dependence of the boundary-layer

Table 14. LOWTRAN CARD 1 Input Parameters: MODEL, ITYPE, IEMSCT, and NOPRT

CARD 1	MODEL, ITYPE, IEMSCT, M1, M2, M3, IM, NOPRT, TBOUND, SALB FORMAT(8I5,2F10.3)						
COL 5	MODEL	COL 10	ITYPE	COL 15	IEMSCT	COL 40	NOPRT
0	User-defined*	1	Horizontal path	0	Transmittance	0	Normal output
1	Tropical	2	Slant path H1 to H2	1	Radiance	1	Short output
2	Midlatitude summer	3	Slant path to space	2	Radiance with solar/lunar scattering		
3	Midlatitude winter			3	Transmitted solar irradiance		
4	Subarctic summer						
5	Subarctic winter						
6	1962 U.S. standard						
7	User-defined*						

M1, M2, M3, IM, TBOUND, and SALB are left blank for standard cases.

*Options for non-standard models.

Refer to Section 10.3 for non-standard cases.

aerosol extinction coefficients is based on the water vapor content of the model atmosphere selected by MODEL. ISEASN selects the seasonal dependence of the profiles for both the tropospheric (2 to 10 km) and stratospheric (10 to 30 km) aerosols. IVULCN is used to select both the profile and extinction type for the stratospheric aerosols and to determine transition profiles above the stratosphere to 100 km. VIS, the meteorological range, when specified, will supersede the default meteorological range in the boundary-layer aerosol profile set by IHAZE.

IHAZE = 0 no aerosol attenuation included in the calculation.
= 1 RURAL extinction, default VIS = 23 km.
= 2 RURAL extinction, default VIS = 5 km.
= 3 NAVY MARITIME extinction, sets own VIS.
= 4 MARITIME extinction, default VIS = 23 km (LOWTRAN 5 model).
= 5 URBAN extinction, default VIS = 5 km.
= 6 TROPOSPHERIC extinction, default VIS = 50 km.
= 7 USER-DEFINED extinction, default VIS = 23 km (read into the program as CARD2D).
= 8 FOG1 (advection fog) extinction, default VIS = 0.2 km.
= 9 FOG2 (radiation fog) extinction, default VIS = 0.5 km.

As noted, IHAZE selects the type of extinction and a default meteorological range for the boundary-layer aerosol models only. If VIS is also specified it will override the default IHAZE value. Interpolation of the extinction coefficients based on relative humidity is performed only for the RURAL, MARITIME, URBAN, and TROPOSPHERIC coefficients used in the boundary layer (0- to 2-km altitude).

ISEASN = 0 season determined by the value of MODEL;
SPRING-SUMMER for MODEL = 0, 1, 2, 4, 6, 7
FALL-WINTER for MODEL = 3, 5
= 1 SPRING-SUMMER
= 2 FALL-WINTER

ISEASN selects the appropriate seasonal aerosol profile for both the tropospheric and stratospheric aerosols. Only the tropospheric aerosol extinction coefficients are used with the 2- to 10-km profiles.

IVULCN = 0, 1 BACKGROUND STRATOSPHERIC profile and extinction
= 2 MODERATE VOLCANIC profile and AGED VOLCANIC extinction
= 3 HIGH VOLCANIC profile and FRESH VOLCANIC extinction
= 4 HIGH VOLCANIC profile and AGED VOLCANIC extinction
= 5 MODERATE VOLCANIC profile and FRESH VOLCANIC extinction

The parameter IVULCN controls both the selection of the aerosol profile as well as the type of extinction for the stratospheric aerosols. It also selects appropriate transition profiles above the stratosphere to 100 km. Meteoric dust extinction coefficients are always used for altitudes from 30 to 100 km.

VIS = surface meteorological range (km)* (when specified, supersedes default value set by IHAZE).

ICSTL is the air mass character (1 to 10), only used with the Navy maritime model (IHAZE = 3). Default value is 3.

ICSTL = 1 open ocean

.

.

.

= 10 strong continental influence

See Section 5 for a detailed description of determining the value of ICSTL.

ICIR selects the inclusion of cirrus cloud attenuation in the calculation.

ICIR = 0 no cirrus

= 1 use cirrus profile

See Section 7 for a description of the cirrus cloud model.

IVSA selects the use of the Army (VSA) for aerosols in the boundary layer.

IVSA = 0 not used

= 1 vertical structure algorithm

See Section 6 for a description of utilizing the Army VSA.

WSS = current wind speed (m/s). Only used with the Navy maritime model (IHAZE = 3)

WHH = 24-h average wind speed (m/s). Only used with the Navy maritime model (IHAZE = 3)

---

*The terms "meteorological range" and "visibility" are not always used correctly in the literature. Correctly,[71,72] visibility is the greatest distance at which it is just possible to see and identify with the unaided eye: (a) in the daytime, a dark object against the horizon sky; and (b) at night, a known moderately intense light source. Meteorological range is defined quantitatively, eliminating the subjective nature of the observer and the distinction between day and night. Meteorological range V is defined by the Koschmieder formula

$$V = \frac{1}{\beta} \ln \frac{1}{\varepsilon} = \frac{3.912}{\beta} ,$$

where β is the extinction coefficient, and ε is the threshold contrast, set equal to 0.02. As used in the LOWTRAN computer code, the inputs are in terms of meteorological range, with β, the extinction coefficient, evaluated at 0.55 μm. If only an observer visibility V_{obs} is available, the meteorological range can be estimated as $V \approx (1.3 \pm 0.3) \cdot V_{obs}$.

71. Huschke, R.E., Ed. (1959) Glossary of Meteorology, American Meteorological Society, Boston, Mass.

72. Middleton, W.E.K. (1952) Vision Through the Atmosphere, University of Toronto Press, 250 pp.

If WSS = WHH = 0, default wind speeds set by MODEL.

MODEL	WSS, WHH (m/s)
0	6.90
1	4.10
2	4.10
3	10.29
4	6.69
5	12.35
6	7.20
7	6.90

The use of WSS and WHH are further defined in Section 5.

RAINRT = rain rate (mm/h). Default value is zero.

The use of the parameter RAINRT is explained in Section 8. Table 15 summarizes the use of aerosol control parameters on CARD 2.

10.2.2.1 Optional Cards Following Card 2

Optional input cards after CARD 2 selected by the parameters ICIR, IVSA, MODEL, and IHAZE on CARDS 1 and 2.

CARD 2A CTHIK, CALT, ISEED (ICIR = 1)

Input card for cirrus altitude profile subroutine when ICIR = 1.

CTHIK = cirrus thickness (km)

0 = use thickness statistics

.NE. 0 = user defines thickness

CALT = cirrus base altitude (km)

0 = use calculated value

.NE. 0 = user defines base altitude

ISEED = random number initialization flag. 0 = use default mean values for cirrus, .NE. 0 = initial value of seed for RANF function. Change seed value each run for different random number sequences. This provides for statistical determination of cirrus base altitude and thickness.

CARD 2B ZCVSA, ZTVSA, ZINVSA (IVSA = 1)

Input card for Army VSA subroutine when IVSA = 1. The case is determined by the parameters VIS, ZCVSA, ZTVSA, and ZINVSA.

CASE 1: cloud/fog at the surface; increasing extinction with height from cloud/fog base to cloud/fog top. Selected by VIS $\leq$ 0.5 km and ZCVSA $\geq$ 0.

Use case 2 or 2' below cloud and case 1 inside it.

Table 15. LOWTRAN CARD 2 Input Parameters: IHAZE, ISEASN, IVULCN, VIS

CARD 2			IHAZE, ISEASN, IVULCN, ICSTL, ICIR, IVSA, VIS, WSS, WHH, RAINRT FORMAT (6I5,4F10.3)						
IHAZE			ISEASN		IVULCN				
COL 5	VIS* (KM)	EXTINCTION	COL 10	SEASON	COL 15	SEASON	PROFILE	EXTINCTION	PROFILE/ EXTINCTION
0	<---------- NO AEROSOLS ---------->								
1	23	Rural	0	Set by model		Set by model			Meteoric dust extinction
2	5		1	Spring-summer		Spring-summer			
3	**	Navy maritime	2	Fall-winter		Fall-winter			
4	23	LOWTRAN 5 maritime	Tropospheric profile/ tropospheric extinction		0		Background strato-spheric	Background strato-spheric	Normal atmospheric profile
5	5	Urban			1				
6	50	Tropospheric			2		Moderate volcanic	Aged volcanic	Transition profiles -volcanic to normal
7	23	User-defined			3		High volcanic	Fresh volcanic	
8	0.2	Fog 1			4		High volcanic	Aged volcanic	
9	0.5	Fog 2			5		Moderate volcanic	Fresh volcanic	
0 to 2 km			2 to 10 km		10 to 30 km				30 to 100 km

*Default VIS, can be overriden by VIS > 0 on CARD 2

**Sets own default VIS, see Section 5

CASE 2: hazy/lightly foggy; increasing extinction with height up to the cloudbase. Selected by $0.5 < VIS \leq 10$ km, ZCVSA ≥ 0.

CASE 2': clear/hazy; increasing extinction with height, but less so than case 2, up to the cloudbase. Selected by VIS > 10 km, ZCVSA ≥ 0.

CASE 3: no cloud ceiling but a radiation fog or an inversion or boundary layer present; decreasing extinction with height up to the height of the fog or layer. Selected by ZCVSA < 0, ZINVSA ≥ 0.

CASE 4: no cloud ceiling or inversion layer; constant extinction with height. Selected by ZCVSA < 0 and ZINVSA < 0.

ZCVSA = cloud ceiling height (km):

> 0.0 the known cloud ceiling height;

= 0.0 height unknown: the program will calculate one for case 2, and default is 1.8 km for case 2'; or

< 0.0 no cloud ceiling (cases 3 and 4).

ZTVSA = the thickness of the cloud (case 2) or the thickness of the fog at the surface (case 1) (km):

> 0.0 the known value of the cloud thickness;

= 0.0 thickness unknown: default is 0.2 km.

ZINVSA = the height of the inversion or boundary layer (km):

> 0.0 the known height of the inversion layer;

= 0.0 height unknown: default is 2 km, 0.2 km for fog;

< 0.0 no inversion layer (case 4, if ZCVSA < 0.0 also).

CARD 2C1 ML, TITLE (MODEL = 7) (IM = 1)

A new atmospheric profile can be read in provided the parameters MODEL and IM are set equal to 7 and 1 respectively on CARD 1.

ML = number of atmospheric boundaries to be read in. (maximum of 34)

TITLE = identification of new atmospheric profiles, up to 72 characters.

CARD 2C2 (ML cards)

Z, P, T, DP, RH, WH, WO, AHAZE, VIS1, IHA1, ISEA1, IVUL1

Z = altitude (km)

P = pressure (mb)

T = ambient temperature (^{o}C)

DP = dewpoint temperature (^{o}C)

RH = relative humidity (%)

WH = water vapor density (gm m^{-3})

WO = ozone density (gm m^{-3})

AHAZE = aerosol scaling factor (normalized by the user to the required meteorological range using the LOWTRAN extinction coefficients)

VIS1 = meteorological range (km) for the altitude, Z

IHA1 = aerosol extinction and meteorological range control for the altitude, Z

ISEA1 = aerosol season control for the altitude, Z

IVUL1 = aerosol profile and extinction control for the altitude, Z

See Section 10.3 for a more detailed explanation of using MODEL = 7.

CARD 2D (10 cards) (DUMMY, EXTC(1,I), ABSC(1,I), I=1,40) (IHAZE = 7)

User-defined aerosol extinction and absorption coefficients when IHAZE = 7 on CARD 2.

DUMMY = wavelength of aerosol coefficient (μm) (not used by program but should correspond to wavelengths defined in array VX2 in SUBROUTINE EXTDTA)

EXTC(1,I) = user-defined aerosol extinction coefficient

ABSC(1,I) = user-defined aerosol absorption coefficient

10.2.3 CARD 3 - H1, H2, ANGLE, RANGE, BETA, RO, LEN

CARD 3 is used to define the geometrical path parameters for a given problem.

H1 = initial altitude (km)

H2 = final altitude (km) (for ITYPE = 2)

H2 = tangent height (km) (for ITYPE = 3)

It is important to emphasize here that in the radiance mode of program execution (IEMSCT = 1 or 2), H1, the initial altitude, always defines the position of the observer (or sensor). H1 and H2 cannot be used interchangeably as in the transmittance mode.

ANGLE = initial zenith angle (degrees) as measured from H1

RANGE = path length (km)

BETA = earth center angle subtended by H1 and H2 (degrees)

RO = radius of the earth (km) at the particular latitude at which the calculation is to be performed.

If RO is left blank, the program will use the midlatitude value of 6371.23 km if MODEL is set equal to 7. Otherwise, the earth radius for the appropriate standard model atmosphere (specified by MODEL) will be used.

For an ITYPE = 2 path for which H1 > H2 (and by necessity, ANGLE > 90°), two paths are possible: the long path from H1 through the tangent height to H2 and the short path from H1 to H2. LEN selects the type of path in these cases.

LEN = 0 short path (default).

= 1 long path through the tangent height.

It is <u>not</u> necessary to specify every quantity given above; only those that adequately describe the problem according to the parameter ITYPE (as described below).

(1) Horizontal Paths (ITYPE = 1)
   (a) specify H1, RANGE
   (b) if non-standard meteorological data are to be used, that is, if MODEL = 0 on CARD 1, then refer to Section 10.3 for parameters and format of CARD 3.

(2) Slant Paths Between Two Altitudes (ITYPE = 2)
   (a) specify H1, H2, and ANGLE
   (b) specify H1, ANGLE, and RANGE
   (c) specify H1, H2, and RANGE
   (d) specify H1, H2, and BETA

(3) Slant Paths to Space (ITYPE = 3)
   (a) specify H1 and ANGLE
   (b) specify H1 and H2 (for limb-viewing problem where H2 is the tangent height or minimum altitude of the path trajectory).

For cases 2(b) and 2(c), the program will calculate H2 and ANGLE respectively, assuming no refraction; then proceed as for case 2(a). The actual slant path range will differ from the input value. This method of defining the problem should be used when refraction effects are not important; for example, for ranges of a few tens of km at zenith angles less than 80°. For case 2(d), the program will determine the proper value of ANGLE (including the effects of refraction) through an iterative procedure. This method can be used when the geometrical configuration of the source and receiver is known accurately, but the initial zenith angle is not known precisely due to atmospheric refraction effects. Beta is most frequently determined by the user from ground range information.

Table 16 lists the options on CARD 3 provided to the user for the different types of atmospheric paths.

10.2.3.1 Alternate CARD 3 for Horizontal Paths (MODEL = 0, ITYPE = 1)

If meteorological data are to be used for horizontal path atmospheric transmittance calculations, then set MODEL = 0 on CARD 1. The following parameters can then be specified on CARD 3.

CARD 3 H1, P, T, DP, RH, WH, WO, RANGE

Where these parameters refer to altitude (km), pressure (mb), ambient temperature ($^{\circ}$C), dewpoint temperature ($^{\circ}$C), relative humidity (%), water vapor density (gm m^{-3}), ozone density (gm m^{-3}), and path length (km) respectively.

See Section 10.3 for a more detailed explanation of MODEL = 0.

Table 16. Allowable Combinations of Slant Path Parameters

Case	ITYPE	H1	H2	ANGLE	RANGE	BETA	LEN (Optional)
2a(1)	2	*	*	*			(*)
2b(2)	2	*		*	*		
2c(3)	2	*	*		*		
2d(4)	2	*	*			*	
3a	3	*		*			
3b(5)	3	*	*				

(1) LEN option is available only when H1 > H2 and ANGLE > 90°. Otherwise, LEN is set in the program.

(2) H2 calculated assuming no refraction. Calculated RANGE will differ from the input value.

(3) ANGLE calculated assuming no refraction. Calculated RANGE will differ from the input value.

(4) Exact ANGLE is calculated by iteration of the path calculation.

(5) H2 is interpreted as the tangent height. If H2 and ANGLE are both zero, Case 3a is assumed with ANGLE = 0 (that is, vertical path). For a path tangent at the earth's surface, read in a small number for H2, for example, 0.001 km.

10.2.3.2 Alternate CARD 3 for Transmitted Solar Irradiance (IEMSCT = 3)

For calculating directly transmitted solar irradiance, an ITYPE = 3 path is assumed and CARD 3 has the following form:

H1, H2, ANGLE, IDAY, RO

FORMAT (3F10.3, I5, 5X, F10.3)

H1 = altitude of the observer

H2 = tangent height of path to sun

ANGLE = apparent solar zenith angle at H1

IDAY = day of the year, used to correct for variation in the earth-to-sun distance

RO = radius of earth (default according to MODEL)

Either H2 or ANGLE should be specified. If both are given as zero, then a vertical path (ANGLE = 0°) is assumed. If IDAY is not specified, then the mean earth to sun distance is assumed.

If the apparent solar zenith angle is not known for a particular case, then the solar scattering option (IEMSCT = 2) may be used along with for instance, the observers location, day of the year, and time of day to determine the solar zenith angle (see Section 10.2.3.3 of the user instructions). Note that the apparent solar zenith angle is zenith angle at H1 of the refracted path to the sun and is less than the astronomical solar zenith angle. The difference between the two angles is negligible for angles less than 80°.

10.2.3.3 Optional Cards Following CARD 3

Optional input cards after CARD 3 are selected by parameters IEMSCT on CARD 1 and IPH on CARD 3A1.

For a more complete description of the single scattering input parameters see Section 4 and Appendix C.

CARD 3A1 IPARM, IPH, IDAY, ISOURC (IEMSCT = 2)

Input card for solar/lunar scattered radiation when IEMSCT = 2.

IPARM = 0, 1, 2 controls the method of specifying the solar/lunar geometry on CARD 3A2.

IPH determines the type of phase function used in the calculation.

IPH = 0 Henyey-Greenstein aerosol phase function
= 1 user-supplied aerosol phase function (see CARD 3B)
= 2 MIE-generated database of aerosol phase functions for the LOWTRAN models

IDAY = day of the year, that is, from 1 to 365 used to specify earth to sun distance and (IPARM = 1) to specify the sun's location in the sky.

ISOURC = 0 extraterrestrial source is the sun
= 1 extraterrestrial source is the moon

CARD 3A2 PARM1, PARM2, PARM3, PARM4, TIME, PSIPO, ANGLEM, G (IEMSCT = 2)

Input card for solar/lunar scattered radiation when IEMSCT = 2. Definitions of PARM1, PARM2, PARM3, PARM4 determined by value of IPARM on CARD 3A1.

For IPARM = 0

PARM1 = observer latitude (-90° to $+90^{\circ}$)
Note - if ABS(PARM1) is greater than 89.5° the observer is assumed to be at either the north or the south pole. In this case the path azimuth is undefined. The direction of line-of-sight must be specified as the longitude along which the path lies. This quantity rather than the usual azimuth is read in.

PARM2 = observer longitude (0° to 360°)

PARM3 = source (sun or moon) latitude

PARM4 = source (sun or moon) longitude

For IPARM = 1

(IDAY and TIME must be specified, cannot be used with ISOURC = 1)

PARM1 = observer latitude (-90^{o} to $+90^{o}$)

PARM2 = observer longitude (0^{o} to 360^{o})

PARM3, PARM4 are not required

For IPARM = 2

PARM1 = azimuthal angle between the observer's line-of-sight and the observer-to-sun path, measured from the line of sight, positive east of north, between -180^{o} and 180^{o}

PARM2 = the sun's zenith angle

PARM3, PARM4 are not required

REMAINING CONTROL PARAMETERS

TIME = Greenwich time in decimal hours, that is, 8:45 am is 8.75, 5:20 pm is 17.33 etc. (used with IPARM = 1)

PSIPO = path azimuth (degrees east of north, that is, due north is 0.0^{o}, due east is 90.0^{o} etc. (used with IPARM = 0 or 1)

ANGLEM = phase angle of the moon, that is, the angle formed by the sun, moon, and earth (required if ISOURC = 1)

G = asymmetry factor for use with Henycy-Greenstein phase function (used with IPH = 0)

CARD 3B1 NANGLS (IPH = 1)

Input card for user-defined phase functions when IPH = 1.

NANGLS = number of angles for the user-defined phase functions (maximum of 50)

CARD 3B2 (1 to NANGLS) (IPH = 1)
(ANGF(I), F(1,I), F(2,I), F(3,I), F(4,I), I = 1, NANGLS)

Input card for user-defined phase functions when IPH = 1.

ANGF(I) = phase angle in decimal degrees (0.0^{o} to 180.0^{o})

F(1,I) = user-defined phase function at ANGF(I), boundary layer (0 to 2 km)

F(2,I) = user-defined phase function at ANGF(I), troposphere (2 to 10 km)

F(3,I) = user-defined phase function at ANGF(I), stratosphere (10 to 30 km)

F(4,I) = user-defined phase function at ANGF(I), mesosphere (30 to 100 km)

10.2.4 CARD 4 V1, V2, DV

The spectral range and increment of the calculation.

V1 = initial frequency in wavenumber (cm^{-1})

V2 = final frequency in wavenumber (cm^{-1}), where V2 > V1

DV = frequency increment (or step size) (cm^{-1})

(Note that $\nu = 10^4/\lambda$, where ν is the frequency in cm^{-1} and λ is the wavelength in μm, and that DV can only take values that are a multiple of 5 cm^{-1} and that V1 and V2 are reset to the next lowest integer multiple of 5 cm^{-1}.)

10.2.5 CARD 5 IRPT

The control parameter IRPT causes the program to recycle, so that a series of problems can be run with one submission of LOWTRAN.

IRPT = 0 to end program

= 1 to read all data CARDS (1, 2, 3, 4, 5)

= 2 not used

= 3 read CARD 3 (the geometry card) and CARD 5

= 4 read CARD 4 (frequency) and CARD 5

> 4 or IRPT = 2 will cause program to STOP

Thus, if for the same model atmosphere and type of atmospheric path the reader wishes to make further transmittance calculations in different spectral intervals V1' to V2' etc., and for a different step size (DV' etc.), then IRPT is set equal to 4. In this case, the card sequence is as follows and can be repeated as many times as required.

CARD 5 IRPT = 4

CARD 6 V1' V2' DV'

CARD 7 IRPT = 4

CARD 8 V1'' V2'' DV''

CARD 9 IRPT = 0

The final IRPT card should always be a blank or zero. When using the IRPT = 4 option, the wavelength dependence of the refractive index is not changed (use IRPT = 1 option if this is required).

Table 17 summarizes the user-control parameters on CARD 4 and CARD 5.

10.3 Non-Standard Conditions

Two options are available if atmospheric transmittance calculations are required for non-standard conditions. Here non-standard refers to conditions other than those specified by the six model atmospheres provided by LOWTRAN, which

Table 17. LOWTRAN CARD 4 and CARD 5 Input Parameters: V1, V2, DV, IRPT

CARD 4	V1, V2, DV Format (3F10.3)			
	V1 (cm^{-1})	V2 (cm^{-1})	DV (cm^{-1})	Multiple of 5 cm^{-1}
CARD 5	IRPT Format (I5)			

COL 5	IRPT
0	End of program.
1	Read new CARDS 1, 2, 3, 4, and 5.
2	Not used (stops program).
3	Read new CARDS 3 and 5.
4	Read new CARDS 4 and 5.

are selected by the parameter MODEL on CARD 1. These options enable the user to insert:

(1) An additional atmospheric model (MODEL 7), which can be in the form of radiosonde data. The data need not be specified at the same altitudes as in the standard models.

(2) Meteorological conditions for a given horizontal path calculation (MODEL = 0 case).

10.3.1 ADDITIONAL ATMOSPHERIC MODEL (MODEL = 7)

A new model atmosphere can be inserted as CARD 2C and the required multiples of CARD 2C, provided the parameters MODEL and IM are set equal to 7 and 1 respectively on CARD 1. The number of atmospheric levels to be inserted (ML) must also be specified on CARD 2C. Altitude-dependent aerosol control options on the MODEL = 7 cards provide flexibility to the user in modeling aerosol extinction.

The appropriate meteorological parameters and format for the atmospheric data are given below:

Z, P, T, DP, RH, WH, WO, AHAZE, VIS1, IHA1, ISEA1, IVUL1
FORMAT (3F10.3, 2F5.1, 3E10.3, F7.3, 3I1)

Z = altitude (km)

P = pressure (mb)

T = ambient temperature (^{o}C)

DP = dewpoint temperature (^{o}C)

RH = relative humidity (%)

WH = water vapor density (gm m^{-3})

WO = ozone density (gm m^{-3})

AHAZE = aerosol number density (normalized by the user to the required meteorological range using the LOWTRAN extinction coefficients)

VIS1 = meteorological range (km) for the altitude, Z

IHA1 = aerosol extinction and meteorological range control for the altitude, Z

ISEA1 = aerosol season control for the altitude, Z

IVUL1 = aerosol profile and extinction control for the altitude, Z

Note that it is necessary to specify those quantities underlined with a full line and only one of the three quantities underlined with the dashed line. If DP, RH, and WH are left blank then a dewpoint of 0^{o}C is assumed unless the M2 option on CARD 1 is greater than 0.

If the ozone density (WO) is not known then a value can be obtained from one of the standard atmospheric models (for the appropriate latitude and season) by using the parameter M3 on CARD 1.

Also note that for M1 > 0 on CARD 1, both pressure and temperature are interpolated from the model atmosphere (MODEL = M1) for the altitude Z.

For the modeling of the aerosol profiles and extinction coefficients, if AHAZE, VIS1, ISEA1, and IVUL1 are left blank on the MODEL 7 input card, then the aerosol control parameters, IHAZE, ISEASN, IVULCN, and VIS on CARD 2 will control the modeling of the altitude-dependent aerosol parameters as described in Section 10.2. LOWTRAN will use the aerosol models contained in the program and interpolate the profiles to the same altitudes as the radiosonde (or new model atmosphere) data.

The additional aerosol options on the MODEL 7 card provide user flexibility in modeling altitude-dependent aerosols such as low ground fogs, where finer altitude resolution is required to specify the aerosol profile. These options are categorized as follows:

(a) AHAZE > 0, VIS1 = IHA1 = ISEA1 = IVUL1 = 0.

For this case, the program will use the value of AHAZE at the altitude, Z, to define the aerosol profile. The parameters on CARD 2 will be used only to select the type of aerosol extinction coefficients to be used in the 0 to 2 km, 2 to 10 km, 10 to 30 km, and 30 to 100 km altitude regions as in the

MODEL = 1 to 6 cases. VIS on CARD 2 is not used. The user must scale the AHAZE values to the proper sea level meteorological range.

(b) AHAZE > 0, either IHA1 > 0 or IVUL1 > 0, ISEA1 = 0,

where IHA1 = 1 to 9 with the same extinction coefficient options as IHAZE in Section 10.2, and IVUL1 = 1 to 5 with the same extinction coefficient options as IVULCN in Section 10.2. When IHA1 is defined, it will select the type of extinction coefficient to be used with AHAZE at the altitude, Z, and correspondingly when IVUL1 is defined. Only four different altitude regions are allowed for the aerosols in the program. The boundary altitudes are determined from the altitude, Z, on the MODEL 7 card when either IHA1 or IVUL1 changes value. These boundaries do not necessarily have to correspond to the default values in the standard models.

(c) AHAZE = 0, either one or all of the parameters VIS1, IHA1, ISEA1, and IVUL1 defined,

where ISEA1 = 1 or 2 with the same seasonal profile options as ISEASN in Section 10.2. The aerosol profiles and extinction coefficients will be determined by the values of these parameters at each altitude Z. Again, as in (b) only four altitude regions for the aerosols are allowed in the program, with the boundaries of the regions determined by the altitude Z when the control parameters change. Note also that IHA1 takes precedence over IVUL1 in the selection of the type of extinction coefficients.

Using the fog models provided in the LOWTRAN code, these additional aerosol options allow the user to model clouds.

Note that IHAZE must be defined to some initial value greater than zero to calculate aerosol extinction and that at least two altitudes are needed to define an aerosol altitude region.

When using the Navy maritime aerosol model (IHAZE = 3) together with the Vertical Structure Algorithm (VSA) model, some difficulties can arise if run with a user-defined atmosphere (MODEL = 7). This will occur when the user lets the maritime aerosol model determine the meteorological range from wind speed and relative humidity. The problem arises because when MODEL = 7, the maritime model is called after the VSA model, which requires the meteorological range at the surface to be specified. To get around this the user must run LOWTRAN twice: the first time to let the maritime model determine the meteorological range (set VIS = 0.0 and IVSA = 0); and the second time, the actual run, setting VIS equal to the meteorological range determined by the maritime model in the first run.

10.3.2 HORIZONTAL PATHS (MODEL = 0)

If meteorological data are to be used for horizontal path atmospheric transmittance calculations, then set MODEL = 0 on CARD 1. The following parameters can then be specified on CARD 3.

CARD 3 H1, P, T, DP, RH, WH, WO, RANGE (FORMAT 3F10.3, 2F5.1, 2E10.3, F10.3), where the above parameters refer to altitude (km), pressure (mb) ambient temperature (^{o}C), dewpoint temperature (^{o}C), relative humidity (%), water vapor density (gm m^{-3}), ozone density (gm m^{-3}), and path length (km) respectively.

The format for the above card is similar to that used to input radiosonde data (MODEL = 7). Again, it is only necessary to specify the quantities underlined with the solid line and one of the quantities underlined with the dashed line. The ozone density WO can be specified using the parameter M3 on CARD 1 if measurements are not available. In the latter case, a value will be calculated at altitude H1 based on the appropriate model atmosphere selected by M3.

The aerosol control parameters for the MODEL = 0 cases are on CARD 2 as described in Section 10.2.

11. EXAMPLES OF PROGRAM OUTPUT

Six cases representative of the different new options available in LOWTRAN 6, are presented in this section. The input cards for the six cases are listed in Table 18 and the listing of the file OUTPUT (TAPE 6) is in Tables 19 through 24. The TAPE7 output for all six cases is in Table 25.

In the next section, the output for case 1 will be discussed in detail. For the subsequent cases, only the details relevant to the new features will be discussed.

11.1 Case 1: Solar Scattering

This case demonstrates the new air mass calculation and the calculation of the singly-scattered solar radiance. The parameters selected for this case are as follows: the atmospheric profile is the 1962 U.S. Standard and the boundary-layer aerosol model is RURAL with 23-km meteorological range. The path is a slant path from 500 km to the ground with a zenith angle at 500 km of 160^{o}. The sun is used as the source and the sun position is described in terms of the relative path azimuth of 45^{o} and the solar zenith angle of 60^{o}. The earth-to-sun distance is that for day 1 (January 1). The aerosol phase functions are from the

Table 18. Input Cards for the Six Test Cases

```
6      2      2                                   300.0      0.05
1
 500.0         0.0      160.0
2      2      1    0
  45.0        60.0        0.0       0.0         0.0        0.0        0.0        0.0
4000.0      4500.0       10.0
1
1      2
1                    1
   0.0         0.0
   7.0        12.0                500.0
 900.0      1145.0        5.0
1
1      1      0
3
   0.0         0.0        0.0      10.0
 900.0      1145.0        5.0
1
0      1      0
1                                                          10.
   0.0      1013.0       10.0      10.0                       0.3
 900.0      1145.0        5.0
1
6      2      0
6                           1
   0.0         0.0        0.0
   0.0         1.8       45.0
 900.0      1145.0        5.0
1
6      3      3
1
   0.0                   60.0   74
6000.0      7500.0       20.0
0
```

Table 19. Program Output for Case 1

```
                 ***** LOWTRAN 6 *****

CARD 1   *****     6     2     2     0     0     0     0     0   300.000      .050

CARD 2   *****     1     0     0     0     0.    0     0.000     0.000     0.000     0.000

CARD 3   *****   500.000     0.000   160.000     0.000     0.000     0.000    0

CARD 3A1*****      2     2     1     0

CARD 3A2*****     45.000    60.000     0.000     0.000     0.000     0.000     0.000     0.000

CARD 4   *****  4000.000  4500.000    10.000

PROGRAM WILL COMPUTE RADIANCE+SOLAR SCATTERNG

ATMOSPHERIC MODEL
        TEMPERATURE =    6     1962 U S STANDARD
        WATER VAPOR =    6     1962 U S STANDARD
        OZONE       =    6     1962 U S STANDARD

AEROSOL MODEL
        REGIME                       AEROSOL TYPE               PROFILE                    SEASON

        BOUNDARY LAYER (0-2 KM)  RURAL                       23.0 KM VIS AT SEA LEVEL
        TROPOSPHERE  (2-10KM)    TROPOSPHERIC               TROPOSPHERIC               SPRING-SUMMER
        STRATOSPHERE (10-30KM)   BACKGROUND STRATO          BACKGROUND STRATO          SPRING-SUMMER
        UPPER ATMOS (30-100KM)   METEORIC DUST              NORMAL

SLANT PATH, H1 TO H2
        H1     =    500.000 KM
        H2     =      0.000 KM
        ANGLE  =    160.000 DEG
        RANGE  =      0.000 KM
        BETA   =      0.000 DEG
        LEN    =      0

SINGLE SCATTERING CONTROL PARAMETERS SUMMARY

        RELATIVE AZIMUTH =          45.000 DEG EAST OF NORTH
        SOLAR ZENITH =              60.000 DEG
        TIME (<0 UNDEF) =            0.000 GREENWICH TIME
        PATH AZIMUTH =               0.000 DEG EAST OF NORTH
        DAY OF THE YEAR =            1

EXTRATERRESTIAL SOURCE IS THE SUN

PHASE FUNCTION FROM MIE DATA BASE

FREQUENCY RANGE
         V1 =       4000.0 CM-1  (       2.50 MICROMETERS)
         V2 =       4500.0 CM-1  (       2.22 MICROMETERS)
         DV =         10.0 CM-1


ATMOSPHERIC PROFILES
```

Table 19. Program Output for Case 1 (Contd)

I	Z (KM)	P (MB)	T (K)	H2O	CO2+ (SCALED	O3 LOWTRAN	N2 UNITS)	CNTMSLF (MOL/CM2 KM)	MOL SCAT (-)	N-1 (-)	O3 (UV) (ATM CM/KM)
1	0.00	1013.000	288.2	5.758E-01	9.285E-01	2.493E-03	7.378E-01	1.569E+20	9.475E-01	2.724E-04	2.520E-03
2	1.00	898.900	281.7	3.719E-01	7.771E-01	2.387E-03	6.010E-01	7.951E+19	8.601E-01	2.474E-04	2.520E-03
3	2.00	795.000	275.2	2.323E-01	6.474E-01	2.284E-03	4.870E-01	3.791E+19	7.788E-01	2.240E-04	2.520E-03
4	3.00	701.200	268.7	1.302E-01	5.371E-01	2.020E-03	3.927E-01	1.460E+19	7.035E-01	2.024E-04	2.333E-03
5	4.00	616.600	262.2	7.166E-02	4.435E-01	1.774E-03	3.150E-01	5.454E+18	6.340E-01	1.824E-04	2.147E-03
6	5.00	540.500	255.7	3.745E-02	3.646E-01	1.692E-03	2.513E-01	1.846E+18	5.698E-01	1.640E-04	2.147E-03
7	6.00	472.200	249.2	1.992E-02	2.982E-01	1.576E-03	1.994E-01	6.508E+17	5.108E-01	1.470E-04	2.100E-03
8	7.00	411.100	242.7	9.834E-03	2.427E-01	1.632E-03	1.572E-01	1.988E+17	4.566E-01	1.314E-04	2.287E-03
9	8.00	356.500	236.2	5.004E-03	1.963E-01	1.645E-03	1.232E-01	6.490E+16	4.069E-01	1.171E-04	2.427E-03
10	9.00	308.000	229.7	1.703E-03	1.579E-01	2.130E-03	9.586E-02	9.537E+15	3.615E-01	1.041E-04	3.313E-03
11	10.00	265.000	223.3	5.894E-04	1.262E-01	2.557E-03	7.403E-02	1.460E+15	3.199E-01	9.210E-05	4.200E-03
12	11.00	227.000	216.8	2.367E-04	1.002E-01	3.493E-03	5.678E-02	3.031E+14	2.823E-01	8.125E-05	6.067E-03
13	12.00	194.000	216.7	9.275E-05	7.619E-02	4.037E-03	4.150E-02	6.170E+13	2.413E-01	6.947E-05	7.467E-03
14	13.00	165.800	216.7	3.917E-05	5.738E-02	4.028E-03	3.031E-02	1.460E+13	2.063E-01	5.938E-05	7.933E-03
15	14.00	141.700	216.7	1.587E-05	4.397E-02	4.223E-03	2.214E-02	3.180E+12	1.763E-01	5.075E-05	8.867E-03
16	15.00	121.100	216.7	1.181E-05	3.340E-02	4.383E-03	1.617E-02	2.337E+12	1.507E-01	4.337E-05	9.600E-03
17	16.00	103.500	216.7	8.687E-06	2.537E-02	4.710E-03	1.181E-02	1.677E+12	1.288E-01	3.707E-05	1.120E-02
18	17.00	88.500	216.7	6.432E-06	1.929E-02	5.161E-03	8.637E-03	1.219E+12	1.101E-01	3.169E-05	1.307E-02
19	18.00	75.650	216.7	4.720E-06	1.466E-02	5.540E-03	6.311E-03	8.726E+11	9.411E-02	2.709E-05	1.493E-02
20	19.00	64.670	216.7	4.104E-06	1.114E-02	5.691E-03	4.612E-03	8.726E+11	8.045E-02	2.316E-05	1.633E-02
21	20.00	55.200	216.7	3.564E-06	9.470E-03	5.893E-03	3.371E-03	8.726E+11	6.878E-02	1.980E-05	1.773E-02
22	21.00	47.290	217.6	3.371E-06	6.406E-03	5.447E-03	2.451E-03	1.038E+12	5.859E-02	1.687E-05	1.773E-02
23	22.00	40.470	218.6	3.168E-06	4.847E-03	5.248E-03	1.783E-03	1.219E+12	4.991E-02	1.437E-05	1.820E-02
24	23.00	34.670	219.6	3.015E-06	3.675E-03	4.802E-03	1.299E-03	1.464E+12	4.256E-02	1.225E-05	1.773E-02
25	24.00	29.720	220.6	2.803E-06	2.789E-03	4.274E-03	9.483E-04	1.677E+12	3.632E-02	1.046E-05	1.680E-02
26	25.00	25.490	221.6	2.636E-06	2.119E-03	3.792E-03	6.929E-04	1.963E+12	3.101E-02	8.927E-06	1.587E-02
27	30.00	11.970	226.5	7.612E-07	5.476E-04	1.642E-03	1.479E-04	6.508E+11	1.425E-02	4.101E-06	9.333E-03
28	35.00	5.746	236.5	1.624E-07	1.429E-04	6.674E-04	3.193E-05	1.154E+11	6.550E-03	1.885E-06	5.133E-03
29	40.00	2.871	250.4	3.519E-08	3.922E-05	2.227E-04	7.318E-06	2.023E+10	3.091E-03	8.898E-07	2.287E-03
30	45.00	1.491	264.2	9.175E-09	1.157E-05	5.861E-05	1.821E-06	4.615E+09	1.521E-03	4.380E-07	7.933E-04
31	50.00	.798	270.7	1.939E-09	3.747E-06	1.072E-05	5.027E-07	6.490E+08	7.945E-04	2.287E-07	1.867E-04
32	70.00	.055	219.7	2.406E-12	4.660E-08	8.259E-08	3.291E-09	1.014E+05	6.773E-05	1.950E-08	4.013E-05
33	100.00	.000	210.0	1.502E-16	5.420E-12	5.180E-12	1.046E-13	4.507E+00	3.861E-07	1.112E-10	2.007E-09

ATMOSPHERIC PROFILES

I	Z (KM)	P (MB)	T (K)	CNTMFRN MOL/CM2 KM	HNO3 ATM CM/KM	AEROSOL 1 (-)	AEROSOL 2 (-)	AEROSOL 3 (-)	AEROSOL 4 (-)	AER1*RH (-)	CIRRUS (-)	RH (PERCNT)
1	0.00	1013.000	288.2	2.010E+22	0.	1.580E-01	0.	0.	0.	7.250E+00	0.	4.589E+01
2	1.00	898.800	281.7	1.301E+22	0.	9.910E-02	0.	0.	0.	4.861E+00	0.	4.906E+01
3	2.00	795.000	275.2	8.143E+21	0.	6.210E-02	0.	0.	0.	3.230E+00	0.	5.201E+01
4	3.00	701.200	268.7	4.573E+21	0.	0.	3.460E-02	0.	0.	0.	0.	0.
5	4.00	616.500	262.2	2.521E+21	0.	0.	1.850E-02	0.	0.	0.	0.	0.
6	5.00	540.500	255.7	1.319E+21	0.	0.	9.310E-03	0.	0.	0.	0.	0.
7	6.00	472.200	249.2	7.025E+20	0.	0.	7.710E-03	0.	0.	0.	0.	0.
8	7.00	411.100	242.7	3.472E+20	0.	0.	6.230E-03	0.	0.	0.	0.	0.
9	8.00	356.500	236.2	1.763E+20	4.069E-35	0.	3.370E-03	0.	0.	0.	0.	0.
10	9.00	308.000	229.7	6.023E+19	3.615E-06	0.	1.820E-03	0.	0.	0.	0.	0.

Table 19. Program Output for Case 1 (Contd)

11	10.00	265.000	223.3	2.086E+19	1.056E-05	0.	0.	1.140E-03	0.	0.	0.	0.
12	11.00	227.000	216.8	8.384E+18	2.259E-05	0.	0.	7.990E-04	0.	0.	0.	0.
13	12.00	194.000	216.7	3.235E+18	2.896E-05	0.	0.	6.410E-04	0.	0.	0.	0.
14	13.00	165.800	216.7	1.345E+18	2.883E-05	0.	0.	5.170E-04	0.	0.	0.	0.
15	14.00	141.700	216.7	5.364E+17	2.820E-05	0.	0.	4.420E-04	0.	0.	0.	0.
16	15.00	121.100	216.7	3.929E+17	2.712E-05	0.	0.	3.950E-04	0.	0.	0.	0.
17	16.00	103.500	216.7	2.845E+17	2.446E-05	0.	0.	3.820E-04	0.	0.	0.	0.
18	17.00	88.500	216.7	2.074E+17	2.202E-05	0.	0.	4.250E-04	0.	0.	0.	0.
19	18.00	75.650	216.7	1.500E+17	1.975E-05	0.	0.	5.200E-04	0.	0.	0.	0.
20	19.00	64.670	216.7	1.282E+17	1.850E-05	0.	0.	5.810E-04	0.	0.	0.	0.
21	20.00	55.290	216.7	1.096E+17	2.063E-05	0.	0.	5.890E-04	0.	0.	0.	0.
22	21.00	47.290	217.6	1.019E+17	2.153E-05	0.	0.	5.020E-04	0.	0.	0.	0.
23	22.00	40.470	218.6	9.401E+16	2.096E-05	0.	0.	4.200E-04	0.	0.	0.	0.
24	23.00	34.670	219.6	8.788E+16	2.213E-05	0.	0.	3.000E-04	0.	0.	0.	0.
25	24.00	29.720	220.5	8.025E+16	2.173E-05	0.	0.	1.980E-04	0.	0.	0.	0.
26	25.00	25.490	221.6	7.414E+16	1.17[illegible]E-05	0.	0.	1.310E-04	0.	0.	0.	0.
27	30.00	11.970	226.5	1.961E+16	3.704E-06	0.	0.	3.320E-05	0.	0.	0.	0.
28	35.00	5.746	236.5	3.795E+15	1.441E-07	0.	0.	0.	1.640E-05	0.	0.	0.
29	40.00	2.871	250.4	7.502E+14	3.091E-37	0.	0.	0.	7.990E-06	0.	0.	0.
30	45.00	1.491	264.2	1.764E+14	0.	0.	0.	0.	4.010E-06	0.	0.	0.
31	50.00	.798	270.7	3.454E+13	0.	0.	0.	0.	2.100E-06	0.	0.	0.
32	70.00	.055	219.7	3.680E+10	0.	0.	0.	0.	1.600E-07	0.	0.	0.
33	100.00	.000	210.0	1.399E-06	0.	0.	0.	0.	9.310E-10	0.	0.	0.

```
CASE 2A: GIVEN H1, H2, ANGLE

EITHER A SHORT PATH (LEN=0) OR A LONG PATH THROUGH A TANGENT HEIGHT (LEN=1) IS POSSIBLE: LEN =    0


FROM SUBROUTINE REDUCE:
   ONE OR BOTH OF H1 AND H2 ARE ABOVE THE TOP OF THE ATMOSPHERIC PROFILE ZMAX =     100.000 AND HAVE BEEN RESET TO ZMAX
   ANGLE AND/OR PHI HAVE ALSO BEEN RESET TO THE ZENITH ANGLE AT ZMAX =     158.706 DEG


SLANT PATH PARAMETERS IN STANDARD FORM

        H1      =    100.000 KM
        H2      =      0.000 KM
        ANGLE   =    158.706 DEG
        PHI     =     21.639 DEG
        HMIN    =      0.000 KM
        LEN     =          0

CALCULATION OF THE REFRACTED PATH THROUGH THE ATMOSPHERE


 I       ALTITUDE          THETA  DRANGE    RANGE    DBETA    BETA     PHI    TBEND  BENDING    PBAR    TBAR   RHOBAR
     FROM        TO
     (KM)       (KM)       (DEG)   (KM)     (KM)     (DEG)    (DEG)    (DEG)   (DEG)   (DEG)     (MB)    (K)  (GM CM-3)
```

Table 19. Program Output for Case 1 (Contd)

H2 TO H1

1	0.000	1.000	21.639	1.076	1.076	.004	.004	158.364	.001	.001	955.683	284.99	1.17E-03
2	1.000	2.000	21.636	1.076	2.152	.004	.007	158.367	.001	.001	846.698	278.43	1.06E-03
3	2.000	3.000	21.633	1.076	3.227	.004	.011	158.370	.000	.002	747.913	271.99	9.57E-04
4	3.000	4.000	21.630	1.076	4.303	.004	.014	158.373	.000	.002	658.727	265.43	8.63E-04
5	4.000	5.000	21.627	1.076	5.379	.004	.018	158.376	.000	.002	578.391	258.99	7.77E-04
6	5.000	6.000	21.624	1.076	6.455	.004	.021	158.379	.000	.003	506.204	252.50	6.98E-04
7	6.000	7.000	21.621	1.076	7.530	.004	.025	158.383	.000	.003	441.516	246.00	6.24E-04
8	7.000	8.000	21.617	1.076	8.606	.004	.029	158.386	.000	.004	383.677	239.50	5.57E-04
9	8.000	9.000	21.614	1.076	9.681	.004	.032	158.389	.000	.004	332.137	233.00	4.96E-04
10	9.000	10.000	21.611	1.076	10.757	.004	.036	158.392	.000	.004	286.399	226.55	4.40E-04
11	10.000	11.000	21.608	1.076	11.833	.004	.039	158.396	.000	.004	245.907	220.10	3.89E-04
12	11.000	12.000	21.604	1.076	12.908	.004	.043	158.399	.000	.005	210.499	216.75	3.38E-04
13	12.000	13.000	21.601	1.076	13.984	.004	.046	158.402	.000	.005	179.900	216.70	2.89E-04
14	13.000	14.000	21.598	1.075	15.059	.004	.050	158.406	.000	.005	153.750	216.70	2.47E-04
15	14.000	15.000	21.594	1.075	16.135	.004	.053	158.409	.000	.005	131.400	216.70	2.11E-04
16	15.000	16.000	21.591	1.075	17.210	.004	.057	158.412	.000	.005	112.300	216.70	1.80E-04
17	16.000	17.000	21.588	1.075	18.286	.004	.060	158.416	.000	.005	96.000	216.70	1.54E-04
18	17.000	18.000	21.584	1.075	19.361	.004	.064	158.419	.000	.006	82.075	216.70	1.32E-04
19	18.000	19.000	21.581	1.075	20.436	.004	.068	158.423	.000	.006	70.160	216.70	1.13E-04
20	19.000	20.000	21.577	1.075	21.512	.004	.071	158.426	.000	.006	59.980	216.70	9.62E-05
21	20.000	21.000	21.574	1.075	22.587	.004	.075	158.430	.000	.006	51.293	217.14	8.21E-05
22	21.000	22.000	21.570	1.075	23.662	.004	.078	158.433	.000	.006	43.883	218.09	7.00E-05
23	22.000	23.000	21.567	1.075	24.738	.004	.082	158.437	.000	.006	37.572	219.09	5.95E-05
24	23.000	24.000	21.563	1.075	25.813	.004	.085	158.440	.000	.006	32.197	220.09	5.09E-05
25	24.000	25.000	21.560	1.075	26.888	.004	.089	158.444	.000	.006	27.607	221.09	4.34E-05
26	25.000	30.000	21.556	5.375	32.264	.018	.107	158.461	.000	.006	18.754	223.73	2.79E-05
27	30.000	35.000	21.539	5.375	37.639	.018	.124	158.479	.000	.006	8.880	230.82	1.28E-05
28	35.000	40.000	21.521	5.374	43.013	.018	.142	158.496	.000	.006	4.322	242.52	5.95E-06
29	40.000	45.000	21.504	5.374	48.387	.018	.159	158.514	.000	.006	2.187	256.43	2.85E-06
30	45.000	50.000	21.486	5.373	53.760	.018	.177	158.532	.000	.006	1.146	267.09	1.45E-06
31	50.000	70.000	21.468	21.486	75.246	.070	.247	158.601	.000	.006	.416	253.93	3.81E-07
32	70.000	100.000	21.399	32.210	107.456	.104	.351	158.706	.000	.006	.028	217.85	1.68E-08

CUMULATIVE ABSORBER AMOUNTS FOR THE PATH FROM H1 TO Z

J	Z (KM)	TBAR (K)	H2O (SCALED LOWTRAN UNITS)	CO2+ (SCALED LOWTRAN UNITS)	O3 (SCALED LOWTRAN UNITS)	HNO3 (ATM CM)	O3 UV (ATM CM)	CNTMSLF1 (MOL CM-2)	CNTMSLF2 (MOL CM-2)	CNTMFRN (MOL CM-2)
1	70.000	217.85	8.005E-12	1.657E-07	2.750E-07	0.	1.700E-05	3.260E+05	3.260E+05	1.165E+11
2	50.000	253.93	6.226E-09	1.829E-05	4.726E-05	0.	1.039E-03	1.592E+09	1.592E+09	1.084E+14
3	45.000	267.09	3.124E-08	5.556E-05	1.991E-04	0.	3.292E-03	1.246E+10	1.032E+10	5.758E+14
4	40.000	256.43	1.358E-07	1.773E-04	8.605E-04	8.305E-37	1.087E-02	6.924E+10	6.710E+10	2.706E+15
5	35.000	242.52	5.843E-07	6.062E-04	3.038E-03	1.134E-08	2.979E-02	3.630E+11	3.608E+11	1.280E+16
6	30.000	230.82	2.668E-06	2.227E-03	8.856E-03	5.905E-06	6.755E-02	2.027E+12	2.024E+12	6.457E+16
7	25.000	223.73	1.078E-05	6.489E-03	2.266E-02	4.344E-05	1.337E-01	8.417E+12	8.415E+12	2.850E+17
8	24.000	221.09	1.371E-05	1.109E-02	2.700E-02	6.094E-05	1.513E-01	1.037E+13	1.037E+13	3.679E+17
9	23.000	220.09	1.683E-05	1.454E-02	3.187E-02	8.455E-05	1.693E-01	1.206E+13	1.206E+13	4.583E+17
10	22.000	219.09	2.016E-05	1.910E-02	3.727E-02	1.077E-04	1.892E-01	1.351E+13	1.350E+13	5.560E+17
11	21.000	218.09	2.367E-05	2.511E-02	4.302E-02	1.306E-04	2.085E-01	1.472E+13	1.472E+13	6.613E+17

Table 19. Program Output for Case 1 (Contd)

12	20.000	217.14	2.740E-05	3.306E-02	4.906E-02	1.534E-04	2.276E-01	1.575E+13	1.574E+13	7.749E+17
13	19.000	216.70	3.152E-05	4.353E-02	5.524E-02	1.744E-04	2.459E-01	1.668E+13	1.668E+13	9.026E+17
14	18.000	216.70	3.626E-05	5.732E-02	6.128E-02	1.950E-04	2.627E-01	1.762E+13	1.762E+13	1.052E+18
15	17.000	216.70	4.221E-05	7.547E-02	6.704E-02	2.174E-04	2.777E-01	1.874E+13	1.873E+13	1.242E+18
16	16.000	216.70	5.028E-05	9.933E-02	7.235E-02	2.424E-04	2.908E-01	2.028E+13	2.028E+13	1.505E+18
17	15.000	216.70	6.121E-05	1.307E-01	7.724E-02	2.701E-04	3.021E-01	2.242E+13	2.242E+13	1.866E+18
18	14.000	216.70	7.599E-05	1.721E-01	8.187E-02	2.999E-04	3.121E-01	2.536E+13	2.536E+13	2.362E+18
19	13.000	216.70	1.037E-04	2.265E-01	8.631E-02	3.306E-04	3.212E-01	3.342E+13	3.342E+13	3.308E+18
20	12.000	216.70	1.706E-04	2.982E-01	9.065E-02	3.617E-04	3.294E-01	6.857E+13	6.857E+13	5.624E+18
21	11.000	216.75	3.359E-04	3.924E-01	9.470E-02	3.894E-04	3.367E-01	2.317E+14	2.317E+14	1.144E+19
22	10.000	220.10	7.517E-04	5.137E-01	9.795E-02	4.072E-04	3.422E-01	1.023E+15	1.023E+15	2.616E+19
23	9.000	226.55	1.881E-03	6.658E-01	1.005E-01	4.148E-04	3.463E-01	5.653E+15	5.653E+15	6.609E+19
24	8.000	233.00	5.174E-03	8.556E-01	1.025E-01	4.168E-04	3.494E-01	3.671E+16	3.671E+16	1.825E+20
25	7.000	239.50	1.286E-02	1.091E+00	1.043E-01	4.168E-04	3.519E-01	1.654E+17	1.654E+17	4.541E+20
26	6.000	246.00	2.823E-02	1.381E+00	1.060E-01	4.168E-04	3.543E-01	5.753E+17	5.753E+17	9.954E+20
27	5.000	252.50	5.810E-02	1.736E+00	1.077E-01	4.168E-04	3.565E-01	1.809E+18	1.809E+18	2.049E+21
28	4.000	258.99	1.148E-01	2.169E+00	1.096E-01	4.168E 04	3.589E-01	5.391E+18	5.391E+18	4.045E+21
29	3.000	265.49	2.203E-01	2.695E+00	1.116E-01	4.168E-04	3.613E-01	1.538E+19	1.386E+19	7.752E+21
30	2.000	271.99	4.100E-01	3.330E+00	1.140E-01	4.168E-04	3.639E-01	4.166E+19	3.139E+19	1.441E+22
31	1.000	278.49	7.291E-01	4.094E+00	1.165E-01	4.168E-04	3.666E-01	1.021E+20	6.077E+19	2.558E+22
32	0.000	284.99	1.231E+00	5.009E+00	1.191E-01	4.168E-04	3.693E-01	2.246E+20	9.823E+19	4.311E+22

J	Z (KM)	N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS
1	70.000	1.024E-08	4.199E-04	0.	0.	0.	9.957E-07	0.
2	50.000	2.144E-06	6.763E-03	0.	0.	0.	1.719E-05	0.
3	45.000	7.646E-06	1.277E-02	0.	0.	0.	3.305E-05	0.
4	40.000	2.888E-05	2.467E-02	0.	0.	0.	6.408E-05	0.
5	35.000	1.167E-04	4.943E-02	0.	0.	0.	1.269E-04	0.
6	30.000	5.252E-04	1.027E-01	0.	0.	8.923E-05	1.710E-04	0.
7	25.000	2.422E-03	2.185E-01	0.	0.	4.722E-04	1.710E-04	0.
8	24.000	3.297E-03	2.546E-01	0.	0.	6.466E-04	1.710E-04	0.
9	23.000	4.496E-03	2.970E-01	0.	0.	9.106E-04	1.710E-04	0.
10	22.000	6.139E-03	3.466E-01	0.	0.	1.294E-03	1.710E-04	0.
11	21.000	8.390E-03	4.046E-01	0.	0.	1.788E-03	1.710E-04	0.
12	20.000	1.150E-02	4.731E-01	0.	0.	2.374E-03	1.710E-04	0.
13	19.000	1.576E-02	5.532E-01	0.	0.	3.003E-03	1.710E-04	0.
14	18.000	2.158E-02	6.469E-01	0.	0.	3.595E-03	1.710E-04	0.
15	17.000	2.955E-02	7.564E-01	0.	0.	4.103E-03	1.710E-04	0.
16	16.000	4.046E-02	8.846E-01	0.	0.	4.537E-03	1.710E-04	0.
17	15.000	5.509E-02	1.035E+00	0.	0.	4.955E-03	1.710E-04	0.
18	14.000	7.532E-02	1.210E+00	0.	0.	5.404E-03	1.710E-04	0.
19	13.000	1.038E-01	1.415E+00	0.	0.	5.919E-03	1.710E-04	0.
20	12.000	1.421E-01	1.655E+00	0.	0.	6.539E-03	1.710E-04	0.
21	11.000	1.945E-01	1.936E+00	0.	0.	7.311E-03	1.710E-04	0.
22	10.000	2.645E-01	2.266E+00	0.	0.	8.343E-03	1.710E-04	0.
23	9.000	3.553E-01	2.626E+00	0.	9.788E-04	8.956E-03	1.710E-04	0.
24	8.000	4.725E-01	3.039E+00	0.	3.685E-03	8.956E-03	1.710E-04	0.
25	7.000	6.223E-01	3.503E+00	0.	8.692E-03	8.956E-03	1.710E-04	0.
26	6.000	8.135E-01	4.022E+00	0.	1.616E-02	8.956E-03	1.710E-04	0.
27	5.000	1.055E+00	4.603E+00	0.	2.529E-02	8.956E-03	1.710E-04	0.

Table 19. Program Output Case 1 (Contd)

28	4.000	1.358E+00	5.250E+00	0.	3.968E-02	8.956E-03	1.710E-04	0.
29	3.000	1.737E+00	5.969E+00	0.	6.735E-02	8.956E-03	1.710E-04	0.
30	2.000	2.209E+00	6.765E+00	3.340E-02	8.596E-02	8.956E-03	1.710E-04	0.
31	1.000	2.792E+00	7.646E+00	1.186E-01	8.596E-02	8.956E-03	1.710E-04	0.
32	0.000	3.509E+00	8.618E+00	2.544E-01	8.596E-02	8.956E-03	1.710E-04	0.

SUMMARY OF THE GEOMETRY CALCULATION

```
H1      =  100.000 KM
H2      =    0.000 KM
ANGLE   =  158.706 DEG
RANGE   =  107.456 KM
BETA    =     .351 DEG
PHI     =   21.639 DEG
HMIN    =    0.000 KM
BENDING =     .006 DEG
LEN     =        0
```

EQUIVALENT SEA LEVEL TOTAL ABSORBER AMOUNTS

H2O	CO2+	O3	HNO3	O3 UV	CNTMSLF1	CNTMSLF2	CNTMFRN
(SCALED	LOWTRAN UNITS)		(ATM CM)	(ATM CM)	(MOL CM-2)	(MOL CM-2)	(MOL CM-2)
1.231E+00	5.009E+00	1.191E-01	4.168E-04	3.693E-01	2.246E+20	9.823E+19	4.311E+22

N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS	MEAN RH (PRCNT)
3.509E+00	8.618E+00	2.544E-01	8.596E-02	8 956E-03	1.710E-04	0.	48.97

SINGLE SCATTERING POINT TO SOURCE PATHS

SCTTR POINT	SCTTR ALT	SUBTENDED ANGLE	SOLAR ZENITH	PATH ZENITH	RELATIVE AZIMUTH	SCTTR ANGLE	MOLECULAR PHASE F
1	100.00	0.00	60.00	158.71	-45.00	104.09	.639E-01
2	70.00	.10	59.93	158.60	-45.04	104.09	.639E-01
3	50.00	.17	59.88	158.53	-45.07	104.09	.639E-01
4	45.00	.19	59.86	158.51	-45.03	104.09	.639E-01
5	40.00	.21	59.85	158.50	-45.09	104.09	.639E-01
6	35.00	.23	59.84	158.48	-45.09	104.09	.639E-01
7	30.00	.24	59.83	158.46	-45.10	104.09	.639E-01
8	25.00	.26	59.81	158.44	-45.11	104.09	.639E-01
9	24.00	.27	59.81	158.44	-45.11	104.09	.639E-01
10	23.00	.27	59.81	158.44	-45.11	104.09	.639E-01
11	22.00	.27	59.81	158.43	-45.11	104.09	.639E-01
12	21.00	.28	59.80	158.43	-45.11	104.09	.639E-01
13	20.00	.28	59.80	158.43	-45.11	104.09	.639E-01

Table 19. Program Output for Case 1 (Contd)

14	19.00	.28	59.80	158.42	-45.12	104.09	.639E-01
15	18.00	.29	59.80	158.42	-45.12	104.09	.639E-01
16	17.00	.29	59.79	158.42	-45.12	104.09	.639E-01
17	16.00	.29	59.79	158.41	-45.12	104.09	.639E-01
18	15.00	.30	59.79	158.41	-45.12	104.09	.639E-01
19	14.00	.30	59.79	158.41	-45.12	104.09	.639E-01
20	13.00	.30	59.78	158.40	-45.13	104.09	.639E-01
21	12.00	.31	59.78	158.40	-45.13	104.09	.639E-01
22	11.00	.31	59.78	158.40	-45.13	104.09	.639E-01
23	10.00	.32	59.78	158.39	-45.13	104.09	.639E-01
24	9.00	.32	59.77	158.39	-45.13	104.09	.639E-01
25	8.00	.32	59.77	158.39	-45.13	104.09	.639E-01
26	7.00	.33	59.77	158.38	-45.13	104.09	.639E-01
27	6.00	.33	59.77	158.38	-45.14	104.09	.639E-01
28	5.00	.33	59.76	158.38	-45.14	104.09	.639E-01
29	4.00	.34	59.76	158.37	-45.14	104.09	.639E-01
30	3.00	.34	59.76	158.37	-45.14	104.10	.639E-01
31	2.00	.34	59.76	158.37	-45.14	104.10	.639E-01
32	1.00	.35	59.75	158.36	-45.14	104.10	.639E-01
33	0.00	.35	59.75	158.36	-45.14	104.10	.639E-01

RADIANCE(WATTS/CM2-STER-XXX)

FREQ (CM-1)	WAVLEN (MICRN)	ATMOS RADIANCE (CM-1)	(MICRN)	PATH SCATTERED (CM-1)	(MICRN)	GROUND REFLECTED (CM-1)	(MICRN)	TOTAL (CM-1)	(MICPN)	INTEGRAL (CM-1)	TOTAL TRANS
4000.	2.500	5.72E-11	9.15E-08	2.41E-10	3.85E-07	6.29E-11	1.01E-07	3.61E-10	5.77E-07	1.80E-09	.0707
4010.	2.494	5.77E-11	9.29E-08	2.59E-10	4.16E-07	9.00E-11	1.45E-07	4.07E-10	6.54E-07	5.87E-09	.0800
4020.	2.488	6.50E-11	1.05E-07	3.10E-10	5.02E-07	1.69E-10	2.74E-07	5.45E-10	8.80E-07	1.13E-08	.1075
4030.	2.481	8.11E-11	1.32E-07	4.19E-10	6.80E-07	4.34E-10	7.04E-07	9.34E-10	1.52E-06	2.07E-08	.1659
4040.	2.475	9.02E-11	1.62E-07	5.58E-10	9.11E-07	9.07E-10	1.48E-06	1.56E-09	2.55E-06	3.63E-08	.2405
4050.	2.469	1.16E-10	1.91E-07	7.11E-10	1.17E-06	1.58E-09	2.59E-06	2.40E-09	3.94E-06	6.03E-08	.3212
4060.	2.463	1.39E-10	2.30E-07	9.35E-10	1.54E-06	2.76E-09	4.54E-06	3.83E-09	6.31E-06	9.86E-08	.4345
4070.	2.457	1.30E-10	2.16E-07	9.15E-10	1.52E-06	2.66E-09	4.40E-06	3.70E-09	6.13E-06	1.36E-07	.4199
4080.	2.451	9.65E-11	1.61E-07	6.81E-10	1.13E-06	1.47E-09	2.45E-06	2.25E-09	3.74E-06	1.58E-07	.2979
4090.	2.445	1.13E-10	1.89E-07	8.67E-10	1.45E-06	2.43E-09	4.06E-06	3.41E-09	5.70E-06	1.92E-07	.3891
4100.	2.439	1.23E-10	2.06E-07	1.01E-09	1.71E-06	3.29E-09	5.52E-06	4.42E-09	7.44E-06	2.36E-07	.4509
4110.	2.433	1.21E-10	2.04E-07	1.05E-09	1.78E-06	3.51E-09	5.93E-06	4.68E-09	7.91E-06	2.83E-07	.4753
4120.	2.427	1.45E-10	2.46E-07	1.39E-09	2.36E-06	5.75E-09	9.76E-06	7.28E-09	1.24E-05	3.56E-07	.6368
4130.	2.421	1.10E-10	1.87E-07	1.05E-09	1.79E-06	3.49E-09	5.96E-06	4.65E-09	7.94E-06	4.03E-07	.4687
4140.	2.415	1.02E-10	1.75E-07	1.02E-09	1.75E-06	3.29E-09	5.65E-06	4.41E-09	7.57E-06	4.47E-07	.4493
4150.	2.410	1.14E-10	1.96E-07	1.23E-09	2.11E-06	4.63E-09	7.97E-06	5.97E-09	1.03E-05	5.06E-07	.5492
4160.	2.404	1.23E-10	2.12E-07	1.42E-09	2.47E-06	5.99E-09	1.04E-05	7.54E-09	1.31E-05	5.82E-07	.6374
4170.	2.398	1.25E-10	2.18E-07	1.55E-09	2.70E-06	6.98E-09	1.21E-05	8.66E-09	1.51E-05	6.68E-07	.6917
4180.	2.392	1.18E-10	2.06E-07	1.52E-09	2.66E-06	6.68E-09	1.17E-05	8.32E-09	1.45E-05	7.52E-07	.6723
4190.	2.387	1.09E-10	1.92E-07	1.46E-09	2.57E-06	6.22E-09	1.09E-05	7.79E-09	1.37E-05	8.30E-07	.6428
4200.	2.381	1.04E-10	1.84E-07	1.46E-09	2.58E-06	6.16E-09	1.09E-05	7.72E-09	1.39E-05	9.07E-07	.6382
4210.	2.375	1.05E-10	1.87E-07	1.57E-09	2.78E-06	6.96E-09	1.23E-05	8.63E-09	1.53E-05	9.93E-07	.6830
4220.	2.370	1.07E-10	1.90E-07	1.69E-09	3.01E-06	7.92E-09	1.41E-05	9.71E-09	1.73E-05	1.09E-06	.7330
4230.	2.364	1.07E-10	1.91E-07	1.73E-09	3.19E-06	8.65E-09	1.55E-05	1.05E-08	1.89E-05	1.20E-06	.7682
4240.	2.353	1.06E-10	1.90E-07	1.67E-09	3.37E-06	9.46E-09	1.70E-05	1.14E-08	2.06E-05	1.31E-06	.8030
4250.	2.353	9.67E-11	1.75E-07	1.76E-09	3.19E-06	8.42E-09	1.52E-05	1.03E-08	1.86E-05	1.41E-06	.7546
4260.	2.347	9.48E-11	1.72E-07	1.82E-09	3.31E-06	[illegible]	1.61E-05	1.08E-08	1.96E-05	1.52E-06	.7752
4270.	2.342	9.46E-11	1.73E-07	1.92E-09	[illegible]	9.73E-09	1.77E-05	1.17E-08	2.14E-05	1.64E-06	.8130

Table 19. Program Output for Case 1 (Contd)

4280.	2.336	9.23E-11	1.69E-07	1.97E-09	3.61E-06	1.01E-08	1.85E-05	1.22E-08	2.23E-05	1.76E-06	.8290
4290.	2.331	9.14E-11	1.68E-07	2.06E-09	3.79E-06	1.08E-08	1.99E-05	1.30E-08	2.39E-05	1.89E-06	.8614
4300.	2.326	8.47E-11	1.57E-07	1.98E-09	3.66E-06	1.00E-08	1.86E-05	1.21E-08	2.24E-05	2.01E-06	.8258
4310.	2.320	8.24E-11	1.53E-07	2.02E-09	3.75E-06	1.04E-08	1.93E-05	1.25E-08	2.32E-05	2.14E-06	.8393
4320.	2.315	8.25E-11	1.54E-07	2.14E-09	3.99E-06	1.14E-08	2.12E-05	1.36E-08	2.53E-05	2.27E-06	.8837
4330.	2.309	8.03E-11	1.50E-07	2.18E-09	4.09E-06	1.17E-08	2.19E-05	1.39E-08	2.61E-05	2.41E-06	.8981
4340.	2.304	7.74E-11	1.46E-07	2.20E-09	4.15E-06	1.18E-08	2.22E-05	1.41E-08	2.65E-05	2.55E-06	.9028
4350.	2.299	7.43E-11	1.41E-07	2.22E-09	4.20E-06	1.19E-08	2.25E-05	1.42E-08	2.68E-05	2.69E-06	.9030
4360.	2.294	7.17E-11	1.36E-07	2.25E-09	4.27E-06	1.20E-08	2.29E-05	1.43E-08	2.73E-05	2.84E-06	.9092
4370.	2.288	6.91E-11	1.32E-07	2.27E-09	4.34E-06	1.22E-08	2.33E-05	1.45E-08	2.78E-05	2.98E-06	.9153
4380.	2.283	6.66E-11	1.28E-07	2.30E-09	4.41E-06	1.23E-08	2.37E-05	1.47E-08	2.82E-05	3.13E-06	.9200
4390.	2.278	6.41E-11	1.24E-07	2.32E-09	4.47E-06	1.25E-08	2.40E-05	1.48E-08	2.86E-05	3.28E-06	.9235
4400.	2.273	6.17E-11	1.19E-07	2.34E-09	4.53E-06	1.26E-08	2.44E-05	1.50E-08	2.90E-05	3.43E-06	.9269
4410.	2.268	5.94E-11	1.16E-07	2.36E-09	4.59E-06	1.27E-08	2.47E-05	1.51E-08	2.94E-05	3.58E-06	.9307
4420.	2.262	5.71E-11	1.12E-07	2.38E-09	4.64E-06	1.28E-08	2.49E-05	1.52E-08	2.97E-05	3.73E-06	.9320
4430.	2.257	5.48E-11	1.07E-07	2.39E-09	4.68E-06	1.28E-08	2.51E-05	1.52E-08	2.99E-05	3.88E-06	.9320
4440.	2.252	5.27E-11	1.04E-07	2.41E-09	4.75E-06	1.29E-08	2.55E-05	1.54E-08	3.03E-05	4.04E-06	.9352
4450.	2.247	5.07E-11	1.00E-07	2.43E-09	4.82E-06	1.30E-08	2.58E-05	1.55E-08	3.07E-05	4.19E-06	.9381
4460.	2.242	4.87E-11	9.69E-08	2.45E-09	4.88E-06	1.31E-08	2.60E-05	1.56E-08	3.10E-05	4.35E-06	.9386
4470.	2.237	4.66E-11	9.32E-08	2.46E-09	4.91E-06	1.30E-08	2.61E-05	1.56E-08	3.11E-05	4.50E-06	.9366
4480.	2.232	4.47E-11	8.96E-08	2.47E-09	4.95E-06	1.30E-08	2.61E-05	1.55E-08	3.11E-05	4.66E-06	.9339
4490.	2.227	4.26E-11	8.59E-08	2.46E-09	4.97E-06	1.29E-08	2.60E-05	1.54E-08	3.10E-05	4.81E-06	.9279

RADIANCE(WATTS/CM2-STER-XXX)

FREQ	WAVLEN	ATMOS RADIANCE		PATH SCATTERED		GROUND REFLECTED		TOTAL		INTEGRAL	TOTAL
(CM-1)	(MICRN)	(CM-1)	(MICRN)	(CM-1)	(MICRN)	(CM-1)	(MICRN)	(CM-1)	(MICRN)	(CM-1)	TRANS
4500.	2.222	4.06E-11	8.22E-08	2.45E-09	4.96E-06	1.26E-08	2.56E-05	1.51E-08	3.07E-05	4.89E-06	.9190

INTEGRATED ABSORPTION FROM 4000 TO 4500 CM-1 = 154.53 CM-1
AVERAGE TRANSMITTANCE = .6909

INTEGRATED RADIANCE = 4.887E-06 WATTS CM-2 STER-1
MINIMUM RADIANCE = 3.609E-10 WATTS CM-2 STER-1 (CM-1)-1 AT 4000.0 CM-1
MAXIMUM RADIANCE = 1.557E-08 WATTS CM-2 STER-1 (CM-1)-1 AT 4460.0 CM-1
BOUNDARY TEMPERATURE = 300.00 K
BOUNDARY EMISSIVITY = .950

CARD 5 ***** 1

Table 20. Program Output for Case 2

```
                ***** LOWTRAN 6 *****

CARD 1  *****    1    2    0    0    0    0    0    0    0.000    0.000

CARD 2  *****    1    0    0    0    1    0   0.000   0.000    0.000    0.000

CARD 2A *****      0.000     0.000            0
             CIRRUS ATTENUATION INCLUDED
             CIRRUS THICKNESS DEFAULTED TO MEAN VALUE OF         1.000KM
             CIRRUS BASE ALTITUDE DEFAULTED TO MEAN VALUE OF    11.000KM
             PROBABILTY OF CLOUD OCCURRING IS   80.0 PERCENT

CARD 3  *****      7.000     12.000     0.000   500.000    0.000    0.000    0

CARD 4  *****    900.000   1145.000     5.000

PROGRAM WILL COMPUTE TRANSMITTANCE

ATMOSPHERIC MODEL
        TEMPERATURE =     1      TROPICAL MODEL
        WATER VAPOR =     1      TROPICAL MODEL
        OZONE       =     1      TROPICAL MODEL

AEROSOL MODEL
        REGIME                   AEROSOL TYPE           PROFILE                   SEASON

        BOUNDARY LAYER (0-2 KM)  RURAL                   23.0 KM VIS AT SEA LEVEL
        TROPOSPHERE   (2-10KM)   TROPOSPHERIC           TROPOSPHERIC              SPRING-SUMMER
        STRATOSPHERE (10-30KM)   BACKGROUND STRATO      BACKGROUND STRATO         SPRING-SUMMER
        UPPER ATMOS (30-100KM)   METEORIC DUST          NORMAL

SLANT PATH, H1 TO H2
       H1     =       7.000 KM
       H2     =      12.000 KM
       ANGLE  =       0.000 DEG
       RANGE  =     500.000 KM
       BETA   =       0.000 DEG
       LEN    =       0

FREQUENCY RANGE
        V1 =         900.0 CM-1  (      11.11 MICROMETERS)
        V2 =        1145.0 CM-1  (       8.73 MICROMETERS)
        DV =           5.0 CM-1


ATMOSPHERIC PROFILES

  I     Z       P        T       H2O       CO2+       O3        N2      CNTMSLF   MOL SCAT     N-1      O3 (UV)
      (KM)    (MB)      (K)           (SCALED   LOWTRAN   UNITS)      (MOL/CM2 KM)  (-)        (-)    (ATM CM/KM)

  1   0.00  1013.000  299.7  1.822E+00 8.799E-01 2.565E-03 6.957E-01 1.627E+21 9.112E-01 2.609E-04 2.613E-03
  2   1.00   904.000  293.7  1.135E+00 7.413E-01 2.461E-03 5.711E-01 7.617E+20 8.298E-01 2.379E-04 2.613E-03
  3   2.00   805.000  287.7  7.366E-01 6.225E-01 2.275E-03 4.671E-01 3.898E+20 7.543E-01 2.164E-04 2.520E-03
  4   3.00   715.000  283.7  3.376E-01 5.157E-01 2.055E-03 3.763E-01 9.956E+19 6.794E-01 1.951E-04 2.380E-03
  5   4.00   633.000  277.0  1.432E-01 4.306E-01 1.812E-03 3.057E-01 2.181E+19 6.160E-01 1.771E-04 2.193E-03
  6   5.00   559.000  270.3  8.824E-02 3.583E-01 1.659E-03 2.474E-01 1.014E+19 5.575E-01 1.603E-04 2.100E-03
```

Table 20. Program Output for Case 2 (Contd)

7	6.00	492.000	263.6	4.508E-02	2.966E-01	1.514E-03	1.990E-01	3.256E+18	5.032E-01	1.447E-04	2.007E-03
8	7.00	432.000	257.0	2.243E-02	2.446E-01	1.377E-03	1.593E-01	9.956E+17	4.531E-01	1.303E-04	1.913E-03
9	8.00	378.000	250.3	1.071E-02	2.008E-01	1.248E-03	1.269E-01	2.817E+17	4.071E-01	1.171E-04	1.820E-03
10	9.00	329.000	243.6	4.591E-03	1.635E-01	1.187E-03	1.001E-01	6.490E+16	3.641E-01	1.047E-04	1.820E-03
11	10.00	286.000	237.0	1.707E-03	1.329E-01	1.129E-03	7.886E-02	1.127E+16	3.253E-01	9.356E-05	1.820E-03
12	11.00	247.000	230.1	5.155E-04	1.071E-01	1.126E-03	6.149E-02	1.303E+15	2.894E-01	8.322E-05	1.913E-03
13	12.00	213.000	223.6	1.613E-04	8.594E-02	1.119E-03	4.773E-02	1.623E+14	2.568E-01	7.385E-05	2.007E-03
14	13.00	162.000	217.0	4.258E-05	6.800E-02	1.106E-03	3.645E-02	1.460E+13	2.261E-01	6.503E-05	2.100E-03
15	14.00	156.000	210.3	2.088E-05	5.421E-02	1.047E-03	2.807E-02	4.507E+12	2.000E-01	5.751E-05	2.100E-03
16	15.00	132.000	203.7	1.385E-05	4.229E-02	1.029E-03	2.108E-02	2.603E+12	1.747E-01	5.024E-05	2.193E-03
17	16.00	111.000	197.0	1.013E-05	3.269E-02	9.668E-04	1.567E-02	1.846E+12	1.519E-01	4.368E-05	2.193E-03
18	17.00	93.700	194.8	7.650E-06	2.468E-02	1.329E-03	1.136E-02	1.413E+12	1.297E-01	3.729E-05	3.220E-03
19	18.00	78.900	198.8	5.798E-06	1.777E-02	1.612E-03	7.812E-03	1.127E+12	1.070E-01	3.077E-05	4.200E-03
20	19.00	66.000	202.7	4.836E-06	1.286E-02	2.334E-03	5.407E-03	1.082E+12	8.857E-02	2.547E-05	6.533E-03
21	20.00	55.500	206.7	3.797E-06	9.387E-03	2.955E-03	3.779E-03	9.127E+11	7.369E-02	2.119E-05	8.867E-03
22	21.00	48.000	210.7	3.684E-06	6.874E-03	3.483E-03	2.650E-03	1.172E+12	6.141E-02	1.766E-05	1.120E-02
23	22.00	40.900	214.6	3.163E-06	5.065E-03	3.798E-03	1.872E-03	1.172E+12	5.138E-02	1.478E-05	1.307E-02
24	23.00	35.000	217.0	2.897E-06	3.798E-03	4.069E-03	1.348E-03	1.314E+12	4.348E-02	1.250E-05	1.493E-02
25	24.00	30.000	219.2	2.789E-06	2.960E-03	4.057E-03	9.755E-04	1.623E+12	3.689E-02	1.061E-05	1.587E-02
26	25.00	25.700	221.4	2.697E-06	2.152E-03	3.806E-03	7.053E-04	2.023E+12	3.129E-02	9.000E-06	1.587E-02
27	30.00	12.200	232.3	7.253E-07	5.468E-04	1.975E-03	1.479E-04	5.841E+11	1.416E-02	4.072E-06	1.120E-02
28	35.00	6.000	243.1	1.146E-07	1.484E-04	5.648E-04	3.341E-05	5.454E+10	6.654E-03	1.914E-06	4.293E-03
29	40.00	3.050	254.0	2.390E-08	4.275E-05	1.903E-04	8.084E-06	8.334E+09	3.237E-03	9.310E-07	1.913E-03
30	45.00	1.590	264.8	5.767E-09	1.291E-05	4.612E-05	2.064E-06	1.627E+09	1.619E-03	4.655E-07	6.067E-04
31	50.00	.854	270.2	1.083E-09	4.232E-06	1.185E-05	5.776E-07	1.789E+08	8.520E-04	2.450E-07	2.007E-04
32	70.00	.058	218.9	2.348E-12	5.092E-08	8.424E-08	3.641E-09	8.834E+04	7.130E-05	2.051E-08	4.013E-06
33	100.00	.000	210.0	1.498E-16	5.395E-12	5.175E-12	1.040E-13	4.507E+00	3.851E-07	1.108E-10	2.007E-09

ATMOSPHERIC PROFILES

I	Z (KM)	P (MB)	T (K)	CNTMFRN MOL/CM2 KM	HNO3 ATM CM/KM	AEROSOL 1 (-)	AEROSOL 2 (-)	AEROSOL 3 (-)	AEROSOL 4 (-)	AER1*RH (-)	CIRRUS (-)	RH (PERCNT)
1	0.00	1013.000	299.7	6.109E+22	0.	1.580E-01	0.	0.	0.	1.195E+01	0.	7.563E+01
2	1.00	904.000	293.7	3.831E+22	0.	9.910E-02	0.	0.	0.	7.219E+00	0.	7.284E+01
3	2.00	805.000	287.7	2.502E+22	0.	6.210E-02	0.	0.	0.	4.631E+00	0.	7.458E+01
4	3.00	715.000	283.7	1.147E+22	0.	0.	3.460E-02	0.	0.	0.	0.	0.
5	4.00	633.000	277.0	4.888E+21	0.	0.	1.850E-02	0.	0.	0.	0.	0.
6	5.00	559.000	270.3	3.019E+21	0.	0.	9.310E-03	0.	0.	0.	0.	0.
7	6.00	492.000	263.6	1.546E+21	0.	0.	7.710E-03	0.	0.	0.	0.	0.
8	7.00	432.000	257.0	7.705E+20	0.	0.	6.230E-03	0.	0.	0.	0.	0.
9	8.00	378.000	250.3	3.684E+20	4.071E-35	0.	3.370E-03	0.	0.	0.	0.	0.
10	9.00	329.000	243.6	1.582E+20	3.641E-06	0.	1.820E-03	0.	0.	0.	0.	0.
11	10.00	286.000	237.0	5.891E+19	1.074E-05	0.	0.	1.140E-03	0.	0.	0.	0.
12	11.00	247.000	230.1	1.782E+19	2.315E-05	0.	0.	7.990E-04	0.	0.	7.000E-02	0.
13	12.00	213.000	223.6	5.581E+18	3.082E-05	0.	0.	6.410E-04	0.	0.	0.	0.
14	13.00	182.000	217.0	1.474E+18	3.165E-05	0.	0.	5.170E-04	0.	0.	0.	0.
15	14.00	156.000	210.3	7.244E+17	3.200E-05	0.	0.	4.420E-04	0.	0.	0.	0.
16	15.00	132.000	203.7	4.809E+17	3.144E-05	0.	0.	3.950E-04	0.	0.	0.	0.
17	16.00	111.000	197.0	3.522E+17	2.886E-05	0.	0.	3.820E-04	0.	0.	0.	0.
18	17.00	93.700	194.8	2.630E+17	2.593E-05	0.	0.	4.250E-04	0.	0.	0.	0.
19	18.00	78.900	198.8	1.938E+17	2.247E-05	0.	0.	5.200E-04	0.	0.	0.	0.
20	19.00	66.600	202.7	1.572E+17	2.037E-05	0.	0.	5.810E-04	0.	0.	0.	0.

Table 20. Program Output for Case 2 (Contd)

21	20.00	56.500	206.7	1.201E+17	2.211E-05	0.	0.	5.890E-04	0.	0.	0.	0.
22	21.00	48.000	210.7	1.135E+17	2.272E-05	0.	0.	5.020E-04	0.	0.	0.	0.
23	22.00	40.900	214.6	9.492E+16	2.158E-05	0.	0.	4.200E-04	0.	0.	0.	0.
24	23.00	35.000	217.0	8.505E+16	2.261E-05	0.	0.	3.000E-04	0.	0.	0.	0.
25	24.00	30.000	219.2	8.019E+16	2.214E-05	0.	0.	1.980E-04	0.	0.	0.	0.
26	25.00	25.700	221.4	7.595E+16	1.189E-05	0.	0.	1.310E-04	0.	0.	0.	0.
27	30.00	12.200	232.3	1.846E+16	3.681E-06	0.	0.	3.320E-05	0.	0.	0.	0.
28	35.00	6.000	243.1	2.651E+15	1.464E-07	0.	0.	0.	1.640E-05	0.	0.	0.
29	40.00	3.050	254.0	5.042E+14	3.237E-37	0.	0.	0.	7.990E-06	0.	0.	0.
30	45.00	1.590	264.8	1.114E+14	0.	0.	0.	0.	4.010E-05	0.	0.	0.
31	50.00	.854	270.2	1.944E+13	0.	0.	0.	0.	2.100E-06	0.	0.	0.
32	70.00	.058	218.9	3.616E+10	0.	0.	0.	0.	1.600E-07	0.	0.	0.
33	100.00	.000	210.0	1.395E+06	0.	0.	0.	0.	9.310E-10	0.	0.	0.

CASE 2C: GIVEN H1, H2, RANGE

NOTE: ANGLE IS COMPUTED FROM H1, H2, AND RANGE ASSUMING NO REFRACTION

SLANT PATH PARAMETERS IN STANDARD FORM

```
H1     =    7.000 KM
H2     =   12.000 KM
ANGLE  =   91.670 DEG
PHI    =   92.749 DEG
HMIN   =    3.987 KM
LEN    =        1
```

CALCULATION OF THE REFRACTED PATH THROUGH THE ATMOSPHERE

I	ALTITUDE FROM (KM)	TO (KM)	THETA (DEG)	DRANGE (KM)	RANGE (KM)	DBETA (DEG)	BETA (DEG)	PHI (DEG)	DBEND (DEG)	BENDING (DEG)	PBAR (MB)	TBAR (K)	RHOBAR (GM CM-3)
	TANGENT HEIGHT	H1											
1	3.987	4.000	90.000	13.562	13.562	.122	.122	90.109	.013	.013	633.644	277.06	7.97E-04
2	4.000	5.000	89.891	106.970	120.552	.960	1.082	90.964	.104	.118	605.801	274.59	7.68E-04
3	5.000	6.000	89.036	49.267	169.820	.442	1.524	91.362	.044	.162	527.255	267.18	6.87E-04
4	6.000	7.000	88.638	37.797	207.616	.339	1.863	91.670	.031	.193	462.873	260.45	6.18E-04
	DOUBLE RANGE, BETA, BENDING FOR SYMMETRIC PART OF PATH				415.233		3.727			.386			
	H1 TO H2												
5	7.000	8.000	88.330	31.824	447.056	.285	4.012	91.932	.024	.410	405.519	253.77	5.56E-04
6	8.000	9.000	88.069	27.997	475.053	.251	4.263	92.163	.020	.430	353.837	247.06	4.98E-04
7	9.000	10.000	87.837	25.272	500.325	.227	4.489	92.373	.016	.446	307.721	240.40	4.45E-04
8	10.000	11.000	87.627	23.204	523.529	.208	4.697	92.567	.014	.460	266.648	233.64	3.97E-04

Table 20. Program Output for Case 2 (Contd)

9	11.000	12.000	87.433	21.565	545.094	.193	4.890	92.749	.012	.471	230.103	226.93	3.53E-04

CUMULATIVE ABSORBER AMOUNTS FOR THE PATH FROM H1 TO Z

J	Z (KM)	TBAR (K)	H2O (SCALED LOWTRAN UNITS)	CO2+ (SCALED LOWTRAN UNITS)	O3 (SCALED LOWTRAN UNITS)	HNO3 (ATM CM)	O3 UV (ATM CM)	CNTMSLF1 (MOL CM-2)	CNTMSLF2 (MOL CM-2)	CNTMFRN (MOL CM-2)
1	6.000	260.45	1.241E+00	1.023E+01	5.468E-02	0.	7.413E-02	7.351E+19	7.259E+19	4.258E+22
2	5.000	267.18	4.467E+00	2.640E+01	1.330E-01	0.	1.754E-01	3.817E+20	3.193E+20	1.531E+23
3	4.000	274.59	1.742E+01	6.952E+01	3.207E-01	0.	4.063E-01	2.187E+21	1.393E+21	5.955E+23
4	3.987	277.06	1.937E+01	7.538E+01	3.453E-01	0.	4.361E-01	2.487E+21	1.551E+21	6.623E+23
5	4.000	277.06	2.133E+01	8.123E+01	3.700E-01	0.	4.659E-01	2.787E+21	1.709E+21	7.292E+23
6	5.000	274.59	3.428E+01	1.244E+02	5.577E-01	0.	6.969E-01	4.592E+21	2.782E+21	1.172E+24
7	6.000	267.18	3.751E+01	1.405E+02	6.360E-01	0.	7.981E-01	4.900E+21	3.029E+21	1.282E+24
8	7.000	260.45	3.875E+01	1.508E+02	6.907E-01	0.	8.723E-01	4.973E+21	3.102E+21	1.325E+24
9	8.000	253.77	3.926E+01	1.578E+02	7.325E-01	6.325E-34	9.317E-01	4.992E+21	3.120E+21	1.342E+24
10	9.000	247.06	3.946E+01	1.629E+02	7.666E-01	5.004E-05	9.827E-01	4.996E+21	3.124E+21	1.349E+24
11	10.000	240.40	3.953E+01	1.667E+02	7.958E-01	2.304E-04	1.029E+00	4.997E+21	3.125E+21	1.352E+24
12	11.000	233.64	3.956E+01	1.694E+02	8.220E-01	6.217E-04	1.072E+00	4.997E+21	3.125E+21	1.353E+24
13	12.000	226.93	3.956E+01	1.715E+02	8.462E-01	1.203E-03	1.114E+00	4.997E+21	3.125E+21	1.353E+24

J	Z (KM)	N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS
1	6.000	6.760E+00	1.809E+01	0.	2.634E-01	0.	0.	0.
2	5.000	1.779E+01	4.427E+01	0.	6.836E-01	0.	0.	0.
3	4.000	4.810E+01	1.073E+02	0.	2.252E+00	0.	0.	0.
4	3.987	5.226E+01	1.162E+02	0.	2.505E+00	0.	0.	0.
5	4.000	5.642E+01	1.246E+02	0.	2.757E+00	0.	0.	0.
6	5.000	8.674E+01	1.831E+02	0.	4.326E+00	0.	0.	0.
7	6.000	9.776E+01	2.143E+02	0.	4.746E+00	0.	0.	0.
8	7.000	1.045E+02	2.324E+02	0.	5.010E+00	0.	0.	0.
9	8.000	1.091E+02	2.461E+02	0.	5.159E+00	0.	0.	0.
10	9.000	1.122E+02	2.569E+02	0.	5.230E+00	0.	0.	0.
11	10.000	1.145E+02	2.650E+02	0.	5.253E+00	1.419E-02	0.	0.
12	11.000	1.161E+02	2.727E+02	0.	5.253E+00	3.650E-02	0.	8.019E-01
13	12.000	1.173E+02	2.786E+02	0.	5.253E+00	5.199E-02	0.	1.565E+00

SUMMARY OF THE GEOMETRY CALCULATION

```
H1     =    7.000 KM
H2     =   12.000 KM
ANGLE  =   91.670 DEG
RANGE  =  545.094 KM
BETA   =    4.890 DEG
PHI    =   92.749 DEG
HMIN   =    3.987 KM
```

Table 20. Program Output for Case 2 (Contd)

BENDING = .471 DEG
LEN = 1

EQUIVALENT SEA LEVEL TOTAL ABSORBER AMOUNTS

H2O	CO2+	O3	HNO3 (ATM CM)	O3 UV (ATM CM)	CNTMSLF1 (MOL CM-2)	CNTMSLF2 (MOL CM-2)	CNTMFRN (MOL CM-2)
(SCALED LOWTRAN UNITS)							
3.956E+01	1.715E+02	8.462E-01	1.203E-03	1.114E+00	4.997E+21	3.125E+21	1.353E+24

N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS	MEAN RH (PRCNT)
1.173E+02	2.786E+02	0.	5.253E+00	5.199E-02	0.	1.565E+00	0.00

FREQ CM-1	WAVELENGTH MICRONS	TOTAL TRANS	H2O TRANS	CO2+ TRANS	OZONE TRANS	N2 CONT TRANS	H2O CONT TRANS	MOL SCAT TRANS	AEROSOL TRANS	HNO3 TRANS	AEROSOL ABS	INTEGRATED ABSORPTION
900.	11.111	.0022	.7486	1.0000	1.0000	1.0000	.0727	1.0000	.9410	.9875	.0563	2.494
905.	11.050	.0022	.7306	.9656	1.0000	1.0000	.0763	1.0000	.9410	.9910	.0562	7.483
910.	10.989	.0023	.7245	.9527	1.0000	1.0000	.0801	1.0000	.9407	.9926	.0564	12.472
915.	10.929	.0023	.7215	.9297	1.0000	1.0000	.0838	1.0000	.9394	.9941	.0577	17.461
920.	10.870	.0024	.7336	.9076	.9999	1.0000	.0877	1.0000	.9381	.9966	.0589	22.449
925.	10.811	.0027	.8197	.8737	.9998	1.0000	.0914	1.0000	.9367	1.0000	.0601	27.435
930.	10.753	.0027	.8316	.8380	.9997	1.0000	.0953	1.0000	.9354	1.0000	.0614	32.422
935.	10.695	.0027	.8413	.8010	.9993	1.0000	.0990	1.0000	.9342	1.0000	.0626	37.408
940.	10.638	.0027	.8237	.7739	.9985	1.0000	.1029	1.0000	.9329	1.0000	.0637	42.395
945.	10.582	.0025	.7807	.7525	.9971	1.0000	.1067	1.0000	.9316	1.0000	.0650	47.382
950.	10.526	.0024	.7546	.7405	.9718	1.0000	.1106	1.0000	.9299	1.0000	.0664	52.370
955.	10.471	.0024	.7306	.7465	.9420	1.0000	.1143	1.0000	.9283	1.0000	.0679	57.358
960.	10.417	.0023	.7215	.7435	.9133	1.0000	.1183	1.0000	.9267	1.0000	.0693	62.346
965.	10.363	.0023	.7181	.7405	.8725	1.0000	.1220	1.0000	.9251	1.0000	.0708	67.335
970.	10.309	.0021	.7145	.7156	.8242	1.0000	.1258	1.0000	.9235	1.0000	.0722	72.324
975.	10.256	.0021	.7245	.7156	.7735	1.0000	.1295	1.0000	.9220	1.0000	.0736	77.314
980.	10.204	.0020	.7576	.7465	.6754	1.0000	.1332	1.0000	.9204	1.0000	.0749	82.303
985.	10.152	.0020	.7980	.8032	.5793	1.0000	.1367	1.0000	.9189	1.0000	.0763	87.293
990.	10.101	.0018	.8296	.8660	.4345	1.0000	.1404	1.0000	.9174	1.0000	.0776	92.284
995.	10.050	.0014	.7756	.9245	.3502	1.0000	.1438	1.0000	.9160	1.0000	.0790	97.277
1000.	10.000	.0011	.7245	.9554	.2759	1.0000	.1474	1.0000	.9145	1.0000	.0803	102.272
1005.	9.950	.0009	.6967	.9728	.2309	1.0000	.1507	1.0000	.9065	1.0000	.0879	107.267
1010.	9.901	.0008	.6606	.9673	.1952	1.0000	.1542	1.0000	.8988	1.0000	.0954	112.263
1015.	9.852	.0006	.6151	.9470	.1655	1.0000	.1574	1.0000	.8911	1.0000	.1028	117.260
1020.	9.804	.0005	.6491	.9210	.1474	1.0000	.1607	1.0000	.8836	1.0000	.1101	122.257
1025.	9.756	.0005	.6414	.8839	.1426	1.0000	.1636	1.0000	.8762	1.0000	.1172	127.255
1030.	9.709	.0005	.6530	.8543	.1381	1.0000	.1666	1.0000	.8690	1.0000	.1242	132.252
1035.	9.662	.0004	.6836	.8032	.1025	1.0000	.1692	1.0000	.8618	1.0000	.1310	137.251
1040.	9.615	.0004	.7000	.7663	.1163	1.0000	.1719	1.0000	.8549	1.0000	.1378	142.249
1045.	9.569	.0005	.7072	.7156	.1980	1.0000	.1745	1.0000	.8480	1.0000	.1444	147.245
1050.	9.524	.0004	.6836	.6977	.1251	1.0000	.1771	1.0000	.8412	1.0000	.1509	152.243

Table 20. Program Output for Case 2 (Contd)

1055.	9.479	.0003	.6639	.6813	.1117	1.0000	.1795	1.0000	.8346	1.0000	.1573	157.242
1060.	9.434	.0004	.6193	.6781	.1316	1.0000	.1818	1.0000	.8281	1.0000	.1636	162.240
1065.	9.390	.0004	.5988	.6682	.1685	1.0000	.1835	1.0000	.8217	1.0000	.1698	167.238
1070.	9.346	.0007	.6230	.6426	.2645	1.0000	.1853	1.0000	.8154	1.0000	.1759	172.234
1075.	9.302	.0018	.6303	.6388	.6754	1.0000	.1863	1.0000	.8092	1.0000	.1819	177.225
1080.	9.259	.0023	.6804	.6649	.7735	1.0000	.1873	1.0000	.8031	1.0000	.1878	182.214
1085.	9.217	.0026	.6304	.7345	.7830	1.0000	.1881	1.0000	.7971	1.0000	.1936	187.201
1090.	9.174	.0027	.6491	.7913	.7892	1.0000	.1889	1.0000	.7990	1.0000	.1911	192.188
1095.	9.132	.0028	.6028	.8706	.7892	1.0000	.1893	1.0000	.8060	1.0000	.1833	197.174
1100.	9.091	.0026	.5311	.9227	.7923	1.0000	.1898	1.0000	.8129	1.0000	.1754	202.161
1105.	9.050	.0025	.4794	.9690	.7892	1.0000	.1885	1.0000	.8198	1.0000	.1676	207.148
1110.	9.009	.0024	.4655	.9819	.7830	1.0000	.1873	1.0000	.8268	1.0000	.1598	212.136
1115.	8.969	.0026	.4962	.9910	.7767	1.0000	.1868	1.0000	.8294	1.0000	.1570	217.123
1120.	8.929	.0027	.5311	.9803	.7735	1.0000	.1863	1.0000	.8309	1.0000	.1557	222.110
1125.	8.889	.0029	.5797	.9599	.7702	1.0000	.1849	1.0000	.8323	1.0000	.1544	227.095
1130.	8.850	.0030	.6151	.9335	.7735	1.0000	.1836	1.0000	.8337	1.0000	.1532	232.080
1135.	8.811	.0027	.5712	.8984	.7892	1.0000	.1811	1.0000	.8351	1.0000	.1519	237.067
1140	8.772	.0025	.5440	.8454	.8191	1.0000	.1786	1.0000	.8365	1.0000	.1506	242.055
1145.	8.734	.0022	.5269	.7913	.8483	1.0000	.1735	1.0000	.8378	1.0000	.1494	244.549

TRANSMISSION DUE TO CIRRUS = .0437

INTEGRATED ABSORPTION FROM 900 TO 1145 CM-1 = 244.55 CM-1
AVERAGE TRANSMITTANCE = .0018

CARD 5 ***** 1

Table 21. Program Output for Case 3

```
                 ***** LOWTRAN 6 *****

   CARD 1  *****     1    1    0    0    0    0    0    0      0.000      0.000

   CARD 2  *****     3    0    0    0    0    0      0.000      0.000      0.000      0.000

 MARINE AEROSOL MODEL USED

  WS NOT SPECIFIED, A DEFAULT VALUE IS USED

  WH NOT SPECIFIED, A DEFAULT VALUE IS USED
        WIND SPEED =      4.10 M/SEC
        WIND SPEED (24 HR AVERAGE) =      4.10 M/SEC
        RELATIVE HUMIDITY =     75.63 PERCENT
        AIRMASS CHARACTER =   3

        VIS =       47.02 KM

   CARD 3  *****       0.000      0.000      0.000     10.000      0.000      0.000    0

   CARD 4  *****     900.000   1145.000      5.000

   PROGRAM WILL COMPUTE TRANSMITTANCE

   ATMOSPHERIC MODEL
           TEMPERATURE =     1      TROPICAL MODEL
           WATER VAPOR =     1      TROPICAL MODEL
           OZONE       =     1      TROPICAL MODEL

   AEROSOL MODEL
           REGIME                   AEROSOL TYPE              PROFILE                   SEASON

          BOUNDARY LAYER (0-2 KM)  NAVY MARITIME              47.0 KM VIS AT SEA LEVEL
          TROPOSPHERE   (2-10KM)   TROPOSPHERIC              TROPOSPHERIC              SPRING-SUMMER
          STRATOSPHERE (10-30KM)   BACKGROUND STRATO         BACKGROUND STRATO         SPRING-SUMMER
          UPPER ATMOS (30-100KM)   METEORIC DUST             NORMAL

   HORIZONTAL PATH
           ALTITUDE =       0.000 KM
           RANGE    =      10.000 KM

   FREQUENCY RANGE
            V1 =          900.0 CM-1  (      11.11 MICROMETERS)
            V2 =         1145.0 CM-1  (       8.73 MICROMETERS)
            DV =            5.0 CM-1


   ATMOSPHERIC PROFILES

    I      Z        P        T        H2O       CO2+        O3         N2       CNTMSLF   MOL SCAT      N-1       O3 (UV)
         (KM)     (MB)      (K)           (SCALED  LOWTRAN  UNITS)         (MOL/CM2 KM)   (-)         (-)     (ATM CM/KM)

    1     0.00  1013.000   299.7   1.822E+00 8.799E-01 2.565E-03 6.957E-01 1.627E+21 9.112E-01 2.609E-04 2.613E-03
    2     1.00   904.000   293.7   1.135E+00 7.413E-01 2.461E-03 5.711E-01 7.617E+20 8.298E-01 2.379E-04 2.613E-03
    3     2.00   805.000   287.7   7.386E-01 6.225E-01 2.275E-03 4.671E-01 3.898E+20 7.543E-01 2.164E-04 2.520E-03
    4     3.00   715.000   283.7   3.376E-01 5.157E-01 2.055E-03 3.763E-01 9.956E+19 6.794E-01 1.951E-04 2.380E-03
```

Table 21. Program Output for Case 3 (Contd)

5	4.00	633.000	277.0	1.432E-01	4.306E-01	1.812E-03	3.057E-01	2.181E+19	6.160E-01	1.771E-04	2.193E-03
6	5.00	559.000	270.3	8.824E-02	3.583E-01	1.659E-03	2.474E-01	1.014E+19	5.575E-01	1.603E-04	2.100E-03
7	6.00	492.000	253.6	4.508E-02	2.960E-01	1.514E-03	1.990E-01	3.256E+18	5.032E-01	1.447E-04	2.007E-03
8	7.00	432.000	257.0	2.243E-02	2.446E-01	1.377E-03	1.593E-01	9.956E+17	4.531E-01	1.303E-04	1.913E-03
9	8.00	378.000	250.3	1.071E-02	2.008E-01	1.248E-03	1.269E-01	2.817E+17	4.071E-01	1.171E-04	1.820E-03
10	9.00	329.000	243.6	4.531E-03	1.635E-01	1.167E-03	1.001E-01	6.490E+16	3.641E-01	1.047E-04	1.820E-03
11	10.00	286.000	237.0	1.707E-03	1.329E-01	1.129E-03	7.886E-02	1.127E+16	3.253E-01	9.356E-05	1.820E-03
12	11.00	247.000	230.1	5.155E-04	1.071E-01	1.126E-03	6.149E-02	1.303E+15	2.894E-01	8.322E-05	1.913E-03
13	12.00	213.000	223.6	1.613E-04	8.594E-02	1.119E-03	4.773E-02	1.623E+14	2.568E-01	7.385E-05	2.007E-03
14	13.00	182.000	217.0	4.258E-05	6.800E-02	1.106E-03	3.645E-02	1.460E+13	2.261E-01	6.503E-05	2.100E-03
15	14.00	156.000	210.3	2.088E-05	5.421E-02	1.047E-03	2.807E-02	4.507E+12	2.000E-01	5.751E-05	2.100E-03
16	15.00	132.000	203.7	1.385E-05	4.229E-02	1.029E-03	2.108E-02	2.603E+12	1.747E-01	5.024E-05	2.193E-03
17	16.00	111.000	197.0	1.013E-05	3.269E-02	9.668E-04	1.567E-02	1.846E+12	1.519E-01	4.368E-05	2.193E-03
18	17.00	93.700	194.8	7.650E-06	2.468E-02	1.329E-03	1.136E-02	1.413E+12	1.297E-01	3.729E-05	3.220E-03
19	18.00	78.900	198.8	5.798E-06	1.777E-02	1.612E-03	7.812E-03	1.127E+12	1.070E-01	3.077E-05	4.200E-03
20	19.00	66.600	202.7	4.836E-06	1.286E-02	2.334E-03	5.407E-03	1.082E+12	8.857E-02	2.547E-05	6.533E-03
21	20.00	56.500	206.7	3.797E-06	9.387E-03	2.955E-03	3.779E-03	9.127E+11	7.369E-02	2.119E-05	8.867E-03
22	21.00	48.000	210.7	3.684E-06	6.874E-03	3.483E-03	2.650E-03	1.172E+12	6.141E-02	1.766E-05	1.120E-02
23	22.00	40.900	214.6	3.163E-06	5.065E-03	3.798E-03	1.872E-03	1.172E+12	5.138E-02	1.478E-05	1.307E-02
24	23.00	35.000	217.0	2.897E-06	3.798E-03	4.069E-03	1.346E-03	1.314E+12	4.348E-02	1.250E-05	1.493E-02
25	24.00	30.000	219.2	2.789E-06	2.860E-03	4.057E-03	9.755E-04	1.623E+12	3.689E-02	1.061E-05	1.587E-02
26	25.00	25.700	221.4	2.697E-06	2.152E-03	3.806E-03	7.053E-04	2.023E+12	3.129E-02	9.000E-06	1.587E-02
27	30.00	12.200	232.3	7.253E-07	5.468E-04	1.975E-03	1.479E-04	5.841E+11	1.416E-02	4.072E-06	1.120E-02
28	35.00	6.000	243.1	1.146E-07	1.484E-04	5.648E-04	3.341E-05	5.454E+10	6.654E-03	1.914E-06	4.293E-03
29	40.00	3.050	254.0	2.390E-08	4.275E-05	1.903E-04	6.084E-06	8.334E+09	3.237E-03	9.310E-07	1.913E-03
30	45.00	1.590	264.8	5.767E-09	1.291E-05	4.612E-05	2.064E-06	1.627E+09	1.619E-03	4.655E-07	6.067E-04
31	50.00	.854	270.2	1.083E-09	4.232E-06	1.185E-05	5.776E-07	1.789E+08	8.520E-04	2.450E-07	2.007E-04
32	70.00	.058	218.9	2.348E-12	5.092E-08	8.424E-08	3.641E-09	8.834E+04	7.130E-05	2.051E-08	4.013E-06
33	100.00	.000	210.0	1.498E-16	5.395E-12	5.175E-12	1.040E-13	4.507E+00	3.851E-07	1.108E-10	2.007E-09

ATMOSPHERIC PROFILES

I	Z (KM)	P (MB)	T (K)	CNTMFRN MOL/CM2 KM	HNO3 ATM CM/KM	AEROSOL 1 (-)	AEROSOL 2 (-)	AEROSOL 3 (-)	AEROSOL 4 (-)	AER1*RH (-)	CIRRUS (-)	RH (PERCNT)
1	0.00	1013.000	299.7	6.109E+22	0.	7.116E-02	0.	0.	0.	5.382E+00	0.	7.563E+01
2	1.00	904.000	293.7	3.831E+22	0.	4.461E-02	0.	0.	0.	3.250E+00	0.	7.284E+01
3	2.00	805.000	287.7	2.502E+22	0.	2.795E-02	0.	0.	0.	2.084E+00	0.	7.458E+01
4	3.00	715.000	283.7	1.147E+22	0.	0.	1.568E-02	0.	0.	0.	0.	0.
5	4.00	633.000	277.0	4.888E+21	0.	0.	1.065E-02	0.	0.	0.	0.	0.
6	5.00	559.000	270.3	3.019E+21	0.	0.	9.310E-03	0.	0.	0.	0.	0.
7	6.00	492.000	263.6	1.546E+21	0.	0.	7.710E-03	0.	0.	0.	0.	0.
8	7.00	432.000	257.0	7.705E+20	0.	0.	6.230E-03	0.	0.	0.	0.	0.
9	8.00	378.000	250.3	3.684E+20	4.071E-35	0.	3.370E-03	0.	0.	0.	0.	0.
10	9.00	329.000	243.6	1.582E+20	3.641E-06	0.	1.820E-03	0.	0.	0.	0.	0.
11	10.00	286.000	237.0	5.891E+19	1.074E-05	0.	0.	1.140E-03	0.	0.	0.	0.
12	11.00	247.000	230.1	1.782E+19	2.315E-05	0.	0.	7.990E-04	0.	0.	0.	0.
13	12.00	213.000	223.6	5.591E+18	3.082E-05	0.	0.	6.410E-04	0.	0.	0.	0.
14	13.00	182.000	217.0	1.474E+18	3.165E-05	0.	0.	5.170E-04	0.	0.	0.	0.
15	14.00	156.000	210.3	7.244E+17	3.200E-05	0.	0.	4.420E-04	0.	0.	0.	0.
16	15.00	132.000	203.7	4.809E+17	3.144E-05	0.	0.	3.950E-04	0.	0.	0.	0.
17	16.00	111.000	197.0	3.522E+17	2.886E-05	0.	0.	3.820E-04	0.	0.	0.	0.
18	17.00	93.700	194.8	2.630E+17	2.593E-05	0.	0.	4.250E-04	0.	0.	0.	0.

Table 21. Program Output for Case 3 (Contd)

19	18.00	78.900	198.9	1.938E+17	2.247E-05	0.	0.	5.200E-04	0.	0.	0.	0.
20	19.00	66.600	202.7	1.572E+17	2.037E-05	0.	0.	5.810E-04	0.	0.	0.	0.
21	20.00	56.500	206.7	1.201E+17	2.211E-05	0.	0.	5.890E-04	0.	0.	0.	0.
22	21.00	48.000	210.7	1.135E+17	2.272E-05	0.	0.	5.020E-04	0.	0.	0.	0.
23	22.00	40.900	214.6	9.492E+16	2.158E-05	0.	0.	4.200E-04	0.	0.	0.	0.
24	23.00	35.000	217.0	8.505E+16	2.261E-05	0.	0.	3.000E-04	0.	0.	0.	0.
25	24.00	30.000	219.2	8.019E+16	2.214E-05	0.	0.	1.980E-04	0.	0.	0.	0.
26	25.00	25.700	221.4	7.535E+16	1.139E-05	0.	0.	1.310E-04	0.	0.	0.	0.
27	30.00	12.200	232.3	1.846E+16	3.681E-06	0.	0.	3.320E-05	0.	0.	0.	0.
28	35.00	6.000	243.1	2.651E+15	1.464E-07	0.	0.	0.	1.640E-05	0.	0.	0.
29	40.00	3.050	254.0	5.042E+14	3.237E-37	0.	0.	0.	7.990E-06	0.	0.	0.
30	45.00	1.590	264.8	1.114E+14	0.	0.	0.	0.	4.010E-06	0.	0.	0.
31	50.00	.854	270.2	1.944E+13	0.	0.	0.	0.	2.100E-06	0.	0.	0.
32	70.00	.058	218.9	3.616E+10	0.	0.	0.	0.	1.800E-07	0.	0.	0.
33	100.00	.000	210.0	1.395E+06	0.	0.	0.	0.	9.310E-10	0.	0.	0.

HORIZONTAL PATH AT ALTITUDE = 0.000 KM WITH RANGE = 10.000 KM, MODEL = 1

EQUIVALENT SEA LEVEL TOTAL ABSORBER AMOUNTS

H2O (SCALED LOWTRAN UNITS)	CO2+ (SCALED LOWTRAN UNITS)	O3 (SCALED LOWTRAN UNITS)	HNO3 (ATM CM)	O3 UV (ATM CM)	CNTMSLF1 (MOL CM-2)	CNTMSLF2 (MOL CM-2)	CNTMFRN (MOL CM-2)
1.822E+01	8.799E+00	2.565E-02	0.	2.613E-02	1.627E+22	0.	6.109E+23

N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS	MEAN RH (PRCNT)
6.957E+00	9.112E+00	7.116E-01	0.	0.	0.	0.	75.63

FREQ CM-1	WAVELENGTH MICRONS	TOTAL TRANS	H2O TRANS	CO2+ TRANS	OZONE TRANS	N2 CONT TRANS	H2O CONT TRANS	MOL SCAT TRANS	AEROSOL TRANS	HNO3 TRANS	AEROSOL ABS	INTEGRATED ABSORPTION
900.	11.111	.0069	.8290	1.0000	1.0000	1.0000	.0111	1.0000	.7541	1.0000	.1250	2.493
905.	11.050	.0074	.8169	.9962	1.0000	1.0000	.0120	1.0000	.7531	1.0000	.1231	7.446
910.	10.989	.0080	.8126	.9944	1.0000	1.0000	.0131	1.0000	.7518	1.0000	.1212	12.406
915.	10.929	.0086	.8104	.9907	1.0000	1.0000	.0142	1.0000	.7498	1.0000	.1198	17.363
920.	10.870	.0093	.8190	.9858	1.0000	1.0000	.0155	1.0000	.7478	1.0000	.1185	22.316
925.	10.811	.0107	.8790	.9793	1.0000	1.0000	.0165	1.0000	.7458	1.0000	.1171	27.263
930.	10.753	.0115	.8870	.9713	1.0000	1.0000	.0179	1.0000	.7438	1.0000	.1157	32.205
935.	10.695	.0123	.8936	.9616	1.0000	1.0000	.0192	1.0000	.7419	1.0000	.1144	37.144
940.	10.638	.0128	.8818	.9547	1.0000	1.0000	.0206	1.0000	.7400	1.0000	.1130	42.080
945.	10.582	.0131	.8514	.9494	.9999	1.0000	.0220	1.0000	.7381	1.0000	.1118	47.014
950.	10.526	.0136	.8329	.9462	.9992	1.0000	.0235	1.0000	.7361	1.0000	.1111	51.946
955.	10.471	.0141	.8169	.9470	.9961	1.0000	.0249	1.0000	.7341	1.0000	.1104	56.876
960.	10.417	.0149	.8104	.9470	.9969	1.0000	.0265	1.0000	.7322	1.0000	.1097	61.801
965.	10.363	.0156	.8083	.9462	.9948	1.0000	.0280	1.0000	.7303	1.0000	.1091	66.723
970.	10.309	.0162	.8061	.9400	.9917	1.0000	.0297	1.0000	.7284	1.0000	.1084	71.642
975.	10.256	.0171	.8126	.9400	.9871	1.0000	.0313	1.0000	.7266	1.0000	.1077	76.557

Table 21. Program Output for Case 3 (Contd)

980.	10.204	.0185	.8348	.9478	.9779	1.0000	.0330	1.0000	.7248	1.0000	.1071	81.464
985.	10.152	.0201	.8635	.9622	.9665	1.0000	.0346	1.0000	.7230	1.0000	.1064	86.364
990.	10.101	.0214	.8857	.9774	.9439	1.0000	.0363	1.0000	.7212	1.0000	.1058	91.257
995.	10.050	.0212	.8479	.9896	.9239	1.0000	.0380	1.0000	.7194	1.0000	.1051	96.151
1000.	10.000	.0207	.8126	.9948	.8951	1.0000	.0398	1.0000	.7177	1.0000	.1045	101.048
1005.	9.950	.0205	.7947	.9971	.8701	1.0000	.0415	1.0000	.7163	1.0000	.1053	105.945
1010.	9.901	.0200	.7672	.9964	.8456	1.0000	.0433	1.0000	.7149	1.0000	.1060	110.845
1015.	9.852	.0192	.7326	.9935	.8213	1.0000	.0450	1.0000	.7135	1.0000	.1068	115.749
1020.	9.804	.0200	.7596	.9887	.8010	1.0000	.0468	1.0000	.7122	1.0000	.1075	120.649
1025.	9.756	.0203	.7536	.9813	.7949	1.0000	.0485	1.0000	.7108	1.0000	.1082	125.548
1030.	9.709	.0209	.7622	.9747	.7887	1.0000	.0503	1.0000	.7095	1.0000	.1089	130.443
1035.	9.662	.0204	.7848	.9622	.7339	1.0000	.0519	1.0000	.7082	1.0000	.1096	135.341
1040.	9.615	.0218	.7972	.9527	.7563	1.0000	.0537	1.0000	.7059	1.0000	.1104	140.232
1045.	9.569	.0249	.8018	.9400	.8479	1.0000	.0553	1.0000	.7056	1.0000	.1110	145.108
1050.	9.524	.0227	.7848	.9353	.7597	1.0000	.0570	1.0000	.7043	1.0000	.1117	149.994
1055.	9.479	.0221	.7698	.9307	.7489	1.0000	.0586	1.0000	.7031	1.0000	.1124	154.884
1060.	9.434	.0225	.7356	.9297	.7794	1.0000	.0602	1.0000	.7019	1.0000	.1131	159.771
1065.	9.390	.0238	.7205	.9271	.8238	1.0000	.0617	1.0000	.7006	1.0000	.1138	164.652
1070.	9.346	.0267	.7387	.9210	.8897	1.0000	.0632	1.0000	.6994	1.0000	.1144	169.518
1075.	9.302	.0301	.7447	.9201	.9779	1.0000	.0644	1.0000	.6982	1.0000	.1151	174.358
1080.	9.259	.0328	.7823	.9262	.9871	1.0000	.0657	1.0000	.6970	1.0000	.1157	179.204
1085.	9.217	.0340	.7823	.9447	.9881	1.0000	.0669	1.0000	.6959	1.0000	.1164	184.034
1090.	9.174	.0341	.7596	.9593	.9888	1.0000	.0681	1.0000	.6952	1.0000	.1163	188.863
1095.	9.132	.0336	.7235	.9786	.9888	1.0000	.0691	1.0000	.6948	1.0000	.1158	193.695
1100.	9.091	.0317	.6661	.9892	.9892	1.0000	.0701	1.0000	.6944	1.0000	.1153	198.537
1105.	9.050	.0300	.6218	.9966	.9888	1.0000	.0706	1.0000	.6940	1.0000	.1149	203.387
1110.	9.009	.0297	.6097	.9983	.9881	1.0000	.0712	1.0000	.6936	1.0000	.1144	208.238
1115.	8.969	.0313	.6365	.9992	.9875	1.0000	.0718	1.0000	.6938	1.0000	.1139	213.082
1120.	8.929	.0330	.6661	.9981	.9871	1.0000	.0724	1.0000	.6941	1.0000	.1135	217.917
1125.	3.389	.0348	.7024	.9954	.9868	1.0000	.0726	1.0000	.6944	1.0000	.1131	222.743
1130.	8.850	.0363	.7326	.9913	.9871	1.0000	.0729	1.0000	.6948	1.0000	.1127	227.561
1135.	8.811	.0342	.6956	.9839	.9888	1.0000	.0727	1.0000	.6951	1.0000	.1123	232.390
1140.	8.772	.0329	.6760	.9728	.9913	1.0000	.0726	1.0000	.6954	1.0000	.1119	237.226
1145.	8.734	.0315	.6629	.9593	.9934	1.0000	.0717	1.0000	.6957	1.0000	.1115	239.647

```
INTEGRATED ABSORPTION FROM  900 TO 1145 CM-1 =     239.65 CM-1
AVERAGE TRANSMITTANCE = .0218

CARD 5 *****     1
```

Table 22. Program Output for Case 4

```
                 ***** LOWTRAN 6 *****

CARD 1  *****    0    1    0    0    0    0    0    0     0.000     0.000

CARD 2  *****    1    0    0    0    0    0    0.000     0.000     0.000    10.000

RAIN MODEL CALLED, RAIN RATE =     10.00 MM/HR

CARD 3  *****     0.000  1013.000    10.000  0.0 10.0 0.        0.              .300MODEL ZERO INPUT

   Z          P          T       REL H    H2O        O3                               AEROSOL
  (KM)       (MB)       (K)       (%)   (GM M-3)  (GM M-3)  TYPE                     PROFILE            SEASON

  0.000   1013.000   283.15    10.00 9.392E-01 0.          RURAL                    RURAL


CARD 4  *****   900.000  1145.000     5.000

PROGRAM WILL COMPUTE TRANSMITTANCE

HORIZONTAL PATH
        ALTITUDE =       0.000 KM
        RANGE    =        .300 KM

FRECUENCY RANGE
         V1 =         900.0 CM-1  (      11.11 MICROMETERS)
         V2 =        1145.0 CM-1  (       8.73 MICROMETERS)
         DV =           5.0 CM-1

ATMOSPHERIC PROFILES

 I     Z        P        T         H2O       CO2+        O3         N2      CNTMSLF  MOL SCAT     N-1      O3 (UV)
      (KM)     (MB)     (K)               (SCALED  LOWTRAN  UNITS)         (MOL/CM2 KM)  (-)         (-)   (ATM CM/KM)

 1    0.00 1013.000   283.2  9.239E-02 9.514E-01 0.          7.576E-01 3.976E+18 9.644E-01 2.773E-04 0.

ATMOSPHERIC PROFILES

 I     Z        P        T      CNTMFRN      HNO3     AEROSOL 1 AEROSOL 2 AEROSOL 3 AEROSOL 4 AER1*RH    CIRRUS        RH
      (KM)     (MB)     (K)  MOL/CM2 KM ATM CM/KM    (-)       (-)       (-)       (-)       (-)       (-)       (PERCNT)

 1    0.00 1013.000   283.2  3.277E+21 0.          1.580E-01 0.         0.        0.       1.580E+00 0.        1.000E+01
HORIZONTAL PATH AT ALTITUDE =      0.000 KM WITH RANGE =       .300 KM, MODEL =   0



EQUIVALENT SEA LEVEL TOTAL ABSORBER AMOUNTS

                 H2O          CO2+          O3          HNO3         O3 UV     CNTMSLF1    CNTMSLF2    CNTMFRN
                   (SCALED LOWTRAN UNITS)             (ATM CM)      (ATM CM)  (MOL CM-2)  (MOL CM-2)  (MOL CM-2)
```

Table 22. Program Output for Case 4 (Contd)

2.772E-02	2.854E-01	0.	0.	0.	1.193E+18	4.257E+17	9.832E+20	
N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS	MEAN RH (PRCNT)	
2.273E-01	2.893E-01	4.740E-02	0.	0.	0.	0.	10.00	

FREQ CM-1	WAVELENGTH MICRONS	TOTAL TRANS	H2O TRANS	CO2+ TRANS	OZONE TRANS	N2 CONT TRANS	H2O CONT TRANS	MOL SCAT TRANS	AEROSOL TRANS	HNO3 TRANS	AEROSOL ABS	INTEGRATED ABSORPTION
900.	11.111	.6232	.9980	1.0000	1.0000	1.0000	.9993	1.0000	.9965	1.0000	.0012	.942
905.	11.050	.6229	.9977	.9998	1.0000	1.0000	.9993	1.0000	.9965	1.0000	.0012	2.828
910.	10.989	.6227	.9975	.9997	1.0000	1.0000	.9993	1.0000	.9965	1.0000	.0012	4.714
915.	10.929	.6225	.9975	.9995	1.0000	1.0000	.9993	1.0000	.9964	1.0000	.0013	6.601
920.	10.870	.6225	.9977	.9992	1.0000	1.0000	.9994	1.0000	.9964	1.0000	.0013	8.489
925.	10.811	.6227	.9987	.9986	1.0000	1.0000	.9994	1.0000	.9963	1.0000	.0014	10.376
930.	10.753	.6225	.9990	.9980	1.0000	1.0000	.9994	1.0000	.9963	1.0000	.0014	12.263
935.	10.695	.6219	.9990	.9970	1.0000	1.0000	.9994	1.0000	.9963	1.0000	.0014	14.154
940.	10.638	.6213	.9989	.9963	1.0000	1.0000	.9994	1.0000	.9962	1.0000	.0015	16.047
945.	10.582	.6206	.9983	.9958	1.0000	1.0000	.9994	1.0000	.9952	1.0000	.0015	17.944
950.	10.525	.6202	.9981	.9954	1.0000	1.0000	.9994	1.0000	.9961	1.0000	.0016	19.843
955.	10.471	.6200	.9977	.9956	1.0000	1.0000	.9994	1.0000	.9961	1.0000	.0016	21.743
960.	10.417	.6198	.9975	.9955	1.0000	1.0000	.9994	1.0000	.9960	1.0000	.0016	23.644
965.	10.363	.6197	.9974	.9954	1.0000	1.0000	.9994	1.0000	.9960	1.0000	.0017	25.545
970.	10.309	.6192	.9974	.9947	1.0000	1.0000	.9994	1.0000	.9959	1.0000	.0017	27.449
975.	10.256	.6193	.9975	.9947	1.0000	1.0000	.9994	1.0000	.9959	1.0000	.0017	29.352
980.	10.204	.6202	.9981	.9956	1.0000	1.0000	.9994	1.0000	.9959	1.0000	.0018	31.251
985.	10.152	.6213	.9985	.9970	1.0000	1.0000	.9994	1.0000	.9958	1.0000	.0018	33.145
990.	10.101	.6224	.9989	.9984	1.0000	1.0000	.9994	1.0000	.9958	1.0000	.0018	35.033
995.	10.050	.6226	.9983	.9994	1.0000	1.0000	.9994	1.0000	.9957	1.0000	.0019	36.920
1000.	10.000	.6223	.9975	.9997	1.0000	1.0000	.9994	1.0000	.9957	1.0000	.0019	38.808
1005.	9.950	[illegible]	.9971	.9998	1.0000	1.0000	.9994	1.0000	.9956	1.0000	.0020	40.698
1010.	9.901	.6215	.9964	.9998	1.0000	1.0000	.9995	1.0000	.9955	1.0000	.0021	42.590
1015.	9.852	.6208	.9955	.9996	1.0000	1.0000	.9995	1.0000	.9954	1.0000	.0023	44.486
1020.	9.804	.6210	.9962	.9993	1.0000	1.0000	.9995	1.0000	.9953	1.0000	.0024	46.381
1025.	9.756	.6205	.9961	.9987	1.0000	1.0000	.9995	1.0000	.9951	1.0000	.0025	48.279
1030.	9.709	.6202	.9963	.9983	1.0000	1.0000	.9995	1.0000	.9950	1.0000	.0026	50.178
1035.	9.662	.6198	.9968	.9970	1.0000	1.0000	.9995	1.0000	.9949	1.0000	.0027	52.079
1040.	9.615	.6193	.9971	.9962	1.0000	1.0000	.9995	1.0000	.9948	1.0000	.0028	53.982
1045.	9.569	.6184	.9972	.9947	1.0000	1.0000	.9995	1.0000	.9947	1.0000	.0029	55.890
1050.	9.524	.6178	.9968	.9942	1.0000	1.0000	.9995	1.0000	.9946	1.0000	.0031	57.801
1055	9.479	.6172	.9965	.9936	1.0000	1.0000	.9995	1.0000	.9945	1.0000	.0032	59.715
1060.	9.434	.6165	.9956	.9935	1.0000	1.0000	.9995	1.0000	.9944	1.0000	.0033	61.633
1065.	9.390	.6159	.9952	.9931	1.0000	1.0000	.9995	1.0000	.9944	1.0000	.0034	63.553
1070.	9.346	.6156	.9957	.9922	1.0000	1.0000	.9995	1.0000	.9943	1.0000	.0035	65.475
1075.	9.302	.6156	.9959	.9921	1.0000	1.0000	.9995	1.0000	.9942	1.0000	.0036	67.397
1080.	9.259	.6167	.9968	.9930	1.0000	1.0000	.9995	1.0000	.9941	1.0000	.0037	69.313
1085.	9.217	.6180	.9968	.9952	1.0000	1.0000	.9995	1.0000	.9940	1.0000	.0038	71.223
1090.	9.174	.6186	.9962	.9967	1.0000	1.0000	.9994	1.0000	.9939	1.0000	.0038	73.131
1095.	9.132	.6191	.9952	.9985	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0037	75.035
1100.	9.091	.6186	.9936	.9994	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0036	76.942

Table 22. Program Output for Case 4 (Contd)

1105.	9.050	.6179	.9920	.9998	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0035	78.853
1110.	9.009	.6176	.9915	.9999	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0035	80.765
1115.	8.969	.6183	.9925	1.0000	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0034	82.674
1120.	8.929	.6189	.9936	.9999	1.0000	1.0000	.9994	1.0000	.9941	1.0000	.0034	84.579
1125.	8.889	.6195	.9947	.9997	1.0000	1.0000	.9994	1.0000	.9941	1.0000	.0034	86.481
1130.	8.850	.6199	.9955	.9995	1.0000	1.0000	.9994	1.0000	.9941	1.0000	.0033	88.382
1135.	8.811	.6190	.9945	.9990	1.0000	1.0000	.9994	1.0000	.9942	1.0000	.0033	90.287
1140.	8.772	.6181	.9939	.9981	1.0000	1.0000	.9994	1.0000	.9942	1.0000	.0033	92.198
1145.	8.734	.6169	.9934	.9957	1.0000	1.0000	.9993	1.0000	.9942	1.0000	.0032	93.154

TRANSMISSION DUE TO RAIN = .6271

INTEGRATED ABSORPTION FROM 900 TO 1145 CM-1 = 93.15 CM-1
AVERAGE TRANSMITTANCE = .6198

CARD 5 ***** 1

Table 23. Program Output for Case 5

```
                 ***** LOWTRAN 6 *****

CARD 1  *****    6    2    0    0    0    0    0    0    0.000    0.000

CARD 2  *****    6    0    0    0    0    1    0.000    0.000    0.000    0.000

CARD 2B *****     0.000     0.000     0.000

VERTICAL STRUCTURE ALGORITHM (VSA) USED
                                                   CLOUD CEILING HEIGHT UNKNOWN
                                                   VSA WILL USE A DEFAULT OF 1800.0 METERS

                                                   CLOUD DEPTH UNKNOWN
                                                   VSA WILL USE A DEFAULT OF 200.0 METERS

   HEIGHT(KM)      R.H.(%)      EXTINCTION(KM-1)     VIS(3.912/EXTN)      IHAZE

      0.0000         67.5             .6624E-01            50.0000            6
       .7200         70.2             .9677E-01            35.9667            6
      1.2600         77.4             .2728E+00            13.7360            6
      1.6200         89.5             .1554E+01             2.4976            6
      1.8000        100.0             .7064E+01              .5529            8
      1.8100        100.0             .9880E+01              .3955            8
      1.8200        100.0             .1323E+02              .2955            8
      1.8600        100.0             .3040E+02              .1287            8
      2.0000        100.0             .78[illegible]E+02              .0496            8
MODEL ATMOSPHERE NO. 7
0.         0.          0.        0.0 67.5 0.      0.          .662E-01     0.000  6  0  0
 .720E+00 0.           0.        0.0 70.2 0.      0.          .968E-01     0.000  6  0  0
 .126E+01 0.           0.        0.0 77.4 0.      0.          .273E+00     0.000  6  0  0
 .162E+01 0.           0.        0.0 89.5 0.      0.          .155E+01     0.000  6  0  0
 .180E+01 0.           0.        0.0100.0 0.      0.          .706E+01     0.000  8  0  0
 .181E+01 0.           0.        0.0100.0 0.      0.          .988E+01     0.000  8  0  0
 .182E+01 0.           0.        0.0100.0 0.      0.          .132E+02     0.000  8  0  0
 .186E+01 0.           0.        0.0100.0 0.      0.          .304E+02     0.000  8  0  0
 .200E+01 0.           0.        0.0100.0 0.      0.          .788E+02     0.000  8  0  0
 .201E+01 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .300E+01 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .400E+01 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .500E+01 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .600E+01 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .700E+01 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .800E+01 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .900E+01 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .100E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .110E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .120E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .140E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .160E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .180E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .200E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .220E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .250E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .300E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .350E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
 .400E+02 0.           0.        0.0  0.0 0.      0.        0.             0.000  0  0  0
```

Table 23. Program Output for Case 5 (Contd)

.500E+02	0.	0.	0.0	0.0	0.	0.	0.	0.000	0	0	0
.700E+02	0.	0.	0.0	0.0	0.	0.	0.	0.000	0	0	0
.100E+03	0.	0.	0.0	0.0	0.	0.	0.	0.000	0	0	0

Z (KM)	P (MB)	T (K)	REL H (%)	H2O (GM M-3)	O3 (GM M-3)	TYPE	AEROSOL PROFILE	SEASON
0.000	1013.000	288.20	67.53	8.693E+00	5.400E-05	TROPOSPHERIC	VSA DEFINED	
.720	929.412	283.51	70.17	6.740E+00	5.400E-05	TROPOSPHERIC	VSA DEFINED	
1.260	870.575	280.00	77.37	5.933E+00	5.400E-05	TROPOSPHERIC	VSA DEFINED	
1.620	832.951	277.65	89.47	5.881E+00	5.400E-05	TROPOSPHERIC	VSA DEFINED	
1.800	814.754	276.49	100.00	6.082E+00	5.400E-05	FOG1 (ADVECTTION)	VSA DEFINED	
1.810	813.754	276.42	100.00	6.055E+00	5.400E-05	FOG1 (ADVECTTION)	VSA DEFINED	
1.820	812.756	276.35	100.00	6.029E+00	5.400E-05	FOG1 (ADVECTTION)	VSA DEFINED	
1.850	808.777	276.10	100.00	5.926E+00	5.400E-05	FOG1 (ADVECTTION)	VSA DEFINED	
2.000	795.000	275.20	100.00	5.576E+00	5.400E-05	FOG1 (ADVECTTION)	VSA DEFINED	
2.010	794.003	275.13	51.99	2.856E+00	5.396E-05	TROPOSPHERIC	TROPOSPHERIC	SPRING-SUMMER
3.000	701.200	268.70	50.78	1.800E+00	5.000E-05	TROPOSPHERIC	TROPOSPHERIC	SPRING-SUMMER
4.000	616.600	262.20	50.10	1.100E+00	4.600E-05	TROPOSPHERIC	TROPOSPHERIC	SPRING-SUMMER
5.000	540.500	255.70	48.41	6.400E-01	4.600E-05	TROPOSPHERIC	TROPOSPHERIC	SPRING-SUMMER
6.000	472.200	249.20	49.23	3.800E-01	4.500E-05	TROPOSPHERIC	TROPOSPHERIC	SPRING-SUMMER
7.000	411.100	242.70	48.20	2.100E-01	4.900E-05	TROPOSPHERIC	TROPOSPHERIC	SPRING-SUMMER
8.000	356.500	235.20	50.61	1.200E-01	5.200E-05	TROPOSPHERIC	TROPOSPHERIC	SPRING-SUMMER
9.000	308.000	229.70	37.12	4.600E-02	7.100E-05	TROPOSPHERIC	TROPOSPHERIC	SPRING-SUMMER
10.000	265.000	223.30	28.73	1.800E-02	9.000E-05	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
11.000	227.000	216.80	27.47	8.200E-03	1.300E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
12.000	194.000	216.70	12.54	3.700E-03	1.600E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
14.000	141.700	216.70	2.85	8.400E-04	1.900E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
16.000	103.500	216.70	2.07	6.100E-04	2.400E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
18.000	75.650	216.70	1.49	4.400E-04	3.200E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
20.000	55.290	216.70	1.49	4.400E-04	3.800E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
22.000	40.470	218.60	1.41	5.200E-04	3.900E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
25.000	25.490	221.60	1.27	6.600E-04	3.400E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
30.000	11.970	226.50	.43	3.800E-04	2.000E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
35.000	5.746	236.50	.07	1.600E-04	1.100E-04	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
40.000	2.871	250.40	.01	6.700E-05	4.900E-05	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
50.000	.799	270.70	.00	1.200E-05	4.000E-06	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
70.000	.055	219.70	.00	1.500E-07	8.600E-08	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER
100.000	.000	210.00	0.00	0.	0.	BACKGROUND STRATO	BACKGROUND STRATO	SPRING-SUMMER

```
CARD 3  *****      0.000    1.800    45.000    0.000    0.000    0.000   0

CARD 4  *****    900.000 1145.000     5.000

PROGRAM WILL COMPUTE TRANSMITTANCE

ATMOSPHERIC MODEL
        TEMPERATURE =    6      1962 U S STANDARD
        WATER VAPOR =    6      1962 U S STANDARD
        OZONE       =    6      1962 U S STANDARD

SLANT PATH, H1 TO H2
        H1    =       0.000 KM
```

Table 23. Program Output for Case 5 (Contd)

```
        H2     =        1.800 KM
        ANGLE  =       45.000 DEG
        RANGE  =        0.000 KM
        BETA   =        0.000 DEG
        LEN    =        0

FREQUENCY RANGE
        V1 =          900.0 CM-1  (      11.11 MICROMETERS)
        V2 =         1145.0 CM-1  (       8.73 MICROMETERS)
        DV =            5.0 CM-1
```

ATMOSPHERIC PROFILES

I	Z (KM)	P (MB)	T (K)	H2O	CO2+ (SCALED	O3 LOWTRAN UNITS)	N2	CNTMSLF (MOL/CM2 KM)	MOL SCAT (-)	N-1 (-)	O3 (UV) (ATM CM/KM)
1	0.00	1013.000	288.2	8.474E-01	9.285E-01	2.493E-03	7.378E-01	3.398E+20	9.475E-01	2.720E-04	2.520E-03
2	.72	929.412	283.5	6.133E-01	8.168E-01	2.416E-03	6.366E-01	2.048E+20	8.838E-01	2.538E-04	2.520E-03
3	1.26	870.575	280.0	5.118E-01	7.411E-01	2.360E-03	5.690E-01	1.587E+20	8.382E-01	2.407E-04	2.520E-03
4	1.62	832.951	277.7	4.894E-01	6.939E-01	2.322E-03	5.275E-01	1.559E+20	8.087E-01	2.323E-04	2.520E-03
5	1.80	814.754	276.5	4.971E-01	6.715E-01	2.304E-03	5.079E-01	1.667E+20	7.944E-01	2.281E-04	2.520E-03
6	1.81	813.754	276.4	4.944E-01	6.703E-01	2.303E-03	5.069E-01	1.653E+20	7.936E-01	2.279E-04	2.520E-03
7	1.82	812.756	276.4	4.918E-01	6.690E-01	2.302E-03	5.058E-01	1.638E+20	7.928E-01	2.277E-04	2.520E-03
8	1.86	808.777	276.1	4.814E-01	6.642E-01	2.298E-03	5.015E-01	1.583E+20	7.897E-01	2.268E-04	2.520E-03
9	2.00	795.000	275.2	4.467E-01	6.474E-01	2.284E-03	4.870E-01	1.401E+20	7.788E-01	2.237E-04	2.520E-03
10	2.01	794.003	275.1	2.310E-01	6.462E-01	2.281E-03	4.859E-01	3.755E+19	7.780E-01	2.236E-04	2.518E-03
11	3.00	701.200	268.7	1.302E-01	5.371E-01	2.020E-03	3.927E-01	1.460E+19	7.035E-01	2.022E-04	2.333E-03
12	4.00	616.600	262.2	7.166E-02	4.435E-01	1.774E-03	3.150E-01	5.454E+18	6.340E-01	1.823E-04	2.147E-03
13	5.00	540.500	255.7	3.745E-02	3.646E-01	1.692E-03	2.513E-01	1.846E+18	5.698E-01	1.639E-04	2.147E-03
14	6.00	472.200	249.2	1.992E-02	2.982E-01	1.576E-03	1.994E-01	6.508E+17	5.108E-01	1.469E-04	2.100E-03
15	7.00	411.100	242.7	9.834E-03	2.427E-01	1.632E-03	1.572E-01	1.988E+17	4.566E-01	1.313E-04	2.287E-03
16	8.00	356.500	236.2	5.004E-03	1.963E-01	1.645E-03	1.232E-01	6.490E+16	4.069E-01	1.170E-04	2.427E-03
17	9.00	308.000	229.7	1.703E-03	1.579E-01	2.130E-03	9.586E-02	9.537E+15	3.615E-01	1.040E-04	3.313E-03
18	10.00	265.000	223.3	5.894E-04	1.262E-01	2.557E-03	7.403E-02	1.460E+15	3.199E-01	9.201E-05	4.200E-03
19	11.00	227.000	216.8	2.367E-04	1.002E-01	3.493E-03	5.678E-02	3.031E+14	2.823E-01	8.118E-05	6.067E-03
20	12.00	194.000	216.7	9.275E-05	7.619E-02	4.037E-03	4.150E-02	6.170E+13	2.413E-01	6.941E-05	7.467E-03
21	14.00	141.700	216.7	1.587E-05	4.397E-02	4.228E-03	2.214E-02	3.180E+12	1.763E-01	5.070E-05	8.867E-03
22	16.00	103.500	216.7	8.687E-06	2.537E-02	4.710E-03	1.181E-02	1.677E+12	1.288E-01	3.703E-05	1.120E-02
23	18.00	75.650	216.7	4.726E-06	1.466E-02	5.540E-03	6.311E-03	8.726E+11	9.411E-02	2.707E-05	1.493E-02
24	20.00	55.290	216.7	3.564E-06	8.470E-03	5.803E-03	3.371E-03	8.726E+11	6.878E-02	1.978E-05	1.773E-02
25	22.00	40.470	218.6	3.168E-06	4.847E-03	5.248E-03	1.783E-03	1.219E+12	4.991E-02	1.435E-05	1.820E-02
26	25.00	25.490	221.6	2.636E-06	2.119E-03	3.792E-03	6.929E-04	1.963E+12	3.101E-02	8.918E-06	1.587E-02
27	30.00	11.970	226.5	7.612E-07	5.476E-04	1.642E-03	1.479E-04	6.508E+11	1.425E-02	4.097E-06	9.333E-03
28	35.00	5.746	236.5	1.624E-07	1.429E-04	6.674E-04	3.193E-05	1.154E+11	6.550E-03	1.884E-06	5.133E-03
29	40.00	2.871	250.4	3.540E-08	3.922E-05	2.227E-04	7.318E-06	2.023E+10	3.091E-03	8.889E-07	2.287E-03
30	50.00	.798	270.7	1.939E-09	3.747E-06	1.072E-05	5.027E-07	6.490E+08	7.945E-04	2.285E-07	1.867E-04
31	70.00	.055	219.7	2.406E-12	4.660E-08	8.259E-08	3.291E-09	1.014E+05	6.773E-05	1.948E-08	4.013E-06
32	100.00	.000	210.0	0.	5.395E-12	0.	1.040E-13	0.	3.851E-07	1.108E-10	0.

ATMOSPHERIC PROFILES

I	Z	P	T	CNTMFRN	HNO3	AEROSOL 1	AEROSOL 2	AEROSOL 3	AEROSOL 4	AER1*RH	CIRRUS	RH

Table 23. Program Output for Case 5 (Contd)

	(KM)	(MB)	(K)	MOL/CM2 KM	ATM CM/KM	(-)	(-)	(-)	(-)	(-)	(-)	(PERCNT)
1	0.00	1013.000	288.2	2.946E+22	0.	6.624E-02	0.	0.	0.	4.473E+00	0.	6.753E+01
2	.72	929.412	283.5	2.137E+22	0.	9.677E-02	0.	0.	0.	6.790E+00	0.	7.017E+01
3	1.26	870.575	280.0	1.786E+22	0.	2.728E-01	0.	0.	0.	2.111E+01	0.	7.737E+01
4	1.62	832.951	277.7	1.707E+22	0.	1.554E+00	0.	0.	0.	1.391E+02	0.	8.947E+01
5	1.80	814.754	276.5	1.733E+22	0.	0.	7.064E+00	0.	0.	0.	0.	1.000E+02
6	1.81	813.754	276.4	1.724E+22	0.	0.	9.880E+00	0.	0.	0.	0.	1.000E+02
7	1.82	812.756	276.4	1.715E+22	0.	0.	1.323E+01	0.	0.	0.	0.	1.000E+02
8	1.86	808.777	276.1	1.679E+22	0.	0.	3.040E+01	0.	0.	0.	0.	1.000E+02
9	2.00	795.000	275.2	1.559E+22	0.	0.	7.879E+01	0.	0.	0.	0.	1.000E+02
10	2.01	794.003	275.1	8.096E+21	0.	0.	0.	2.585E-02	0.	0.	0.	0.
11	3.00	701.200	268.7	4.573E+21	0.	0.	0.	1.460E-02	0.	0.	0.	0.
12	4.00	616.600	262.2	2.521E+21	0.	0.	0.	1.020E-02	0.	0.	0.	0.
13	5.00	540.500	255.7	1.319E+21	0.	0.	0.	9.310E-03	0.	0.	0.	0.
14	6.00	472.200	249.2	7.025E+20	0.	0.	0.	7.710E-03	0.	0.	0.	0.
15	7.00	411.100	242.7	3.472E+20	0.	0.	0.	6.230E-03	0.	0.	0.	0.
16	8.00	356.500	236.2	1.768E+20	4.069E-35	0.	0.	3.370E-03	0.	0.	0.	0.
17	9.00	308.000	229.7	6.023E+19	3.615E-06	0.	0.	1.820E-03	0.	0.	0.	0.
18	10.00	265.000	223.3	2.086E+19	1.056E-05	0.	0.	0.	1.140E-03	0.	0.	0.
19	11.00	227.000	216.8	8.384E+18	2.258E-05	0.	0.	0.	7.990E-04	0.	0.	0.
20	12.00	194.000	216.7	3.235E+18	2.896E-05	0.	0.	0.	6.410E-04	0.	0.	0.
21	14.00	141.700	216.7	5.364E+17	2.820E-05	0.	0.	0.	4.420E-04	0.	0.	0.
22	16.00	103.500	216.7	2.845E+17	2.446E-05	0.	0.	0.	3.820E-04	0.	0.	0.
23	18.00	75.650	216.7	1.500E+17	1.976E-05	0.	0.	0.	5.200E-04	0.	0.	0.
24	20.00	55.290	216.7	1.095E+17	2.063E-05	0.	0.	0.	5.890E-04	0.	0.	0.
25	22.00	40.470	218.6	9.401E+16	2.096E-05	0.	0.	0.	4.200E-04	0.	0.	0.
26	25.00	25.490	221.6	7.414E+16	1.178E-05	0.	0.	0.	1.310E-04	0.	0.	0.
27	30.00	11.970	226.5	1.961E+16	3.704E-06	0.	0.	0.	3.320E-05	0.	0.	0.
28	35.00	5.746	236.5	3.796E+15	1.441E-07	0.	0.	0.	1.640E-05	0.	0.	0.
29	40.00	2.871	250.4	7.502E+14	0.	0.	0.	0.	7.990E-06	0.	0.	0.
30	50.00	.798	270.7	3.454E+13	0.	0.	0.	0.	2.100E-06	0.	0.	0.
31	70.00	.055	219.7	3.680E+10	0.	0.	0.	0.	1.600E-07	0.	0.	0.
32	100.00	.000	210.0	0.	0.	0.	0.	0.	0.	0.	0.	0.

CASE 2A: GIVEN H1, H2, ANGLE

SLANT PATH PARAMETERS IN STANDARD FORM

H1	=	0.000 KM
H2	=	1.800 KM
ANGLE	=	45.000 DEG
PHI	=	135.014 DEG
HMIN	=	0.000 KM
LEN	=	0

CALCULATION OF THE REFRACTED PATH THROUGH THE ATMOSPHERE

I	ALTITUDE FROM	TO	THETA	DRANGE	RANGE	DBETA	BETA	PHI	DBEND	BENDING	PBAR	TBAR	RHOBAR

Table 23. Program Output for Case 5 (Contd)

	(KM)	(KM)	(DEG)	(KM)	(KM)	(DEG)	(DEG)	(DEG)	(DEG)	(DEG)	(MB)	(K)	(GM CM-3)
H1 TO H2													
1	0.000	.720	45.000	1.018	1.018	.006	.006	135.005	.001	.001	971.091	285.87	1.18E-03
2	.720	1.260	44.995	.764	1.782	.005	.011	135.010	.001	.002	899.932	281.76	1.11E-03
3	1.260	1.620	44.990	.509	2.291	.003	.015	135.012	.000	.002	851.737	278.83	1.06E-03
4	1.620	1.800	44.988	.255	2.545	.002	.016	135.014	.000	.003	823.846	277.07	1.04E-03

CUMULATIVE ABSORBER AMOUNTS FOR THE PATH FROM H1 TO Z

J	Z (KM)	TBAR (K)	H2O (SCALED LOWTRAN UNITS)	CO2+ (SCALED LOWTRAN UNITS)	O3 (SCALED LOWTRAN UNITS)	HNO3 (ATM CM)	O3 UV (ATM CM)	CNTMSLF1 (MOL CM-2)	CNTMSLF2 (MOL CM-2)	CNTMFRN (MOL CM-2)
1	.720	285.87	7.372E-01	8.873E-01	2.499E-03	0.	2.566E-03	2.715E+20	7.636E+19	2.566E+22
2	1.260	281.76	1.166E+00	1.482E+00	4.322E-03	0.	4.490E-03	4.095E+20	1.309E+20	4.060E+22
3	1.620	278.83	1.420E+00	1.847E+00	5.514E-03	0.	5.773E-03	4.895E+20	1.691E+20	4.949E+22
4	1.800	277.07	1.546E+00	2.021E+00	6.103E-03	0.	6.414E-03	5.306E+20	1.907E+20	5.387E+22

J	Z (KM)	N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS
1	.720	6.984E-01	9.319E-01	8.299E-02	0.	0.	0.	0.
2	1.260	1.158E+00	1.589E+00	2.241E-01	0.	0.	0.	0.
3	1.620	1.437E+00	2.008E+00	6.891E-01	0.	0.	0.	0.
4	1.800	1.569E+00	2.212E+00	8.869E-01	8.989E-01	0.	0.	0.

SUMMARY OF THE GEOMETRY CALCULATION

H1	=	0.000 KM
H2	=	1.800 KM
ANGLE	=	45.000 DEG
RANGE	=	2.545 KM
BETA	=	.016 DEG
PHI	=	135.014 DEG
HMIN	=	0.000 KM
BENDING	=	.003 DEG
LEN	=	0

EQUIVALENT SEA LEVEL TOTAL ABSORBER AMOUNTS

H2O (SCALED LOWTRAN UNITS)	CO2+ (SCALED LOWTRAN UNITS)	O3 (SCALED LOWTRAN UNITS)	HNO3 (ATM CM)	O3 UV (ATM CM)	CNTMSLF1 (MOL CM-2)	CNTMSLF2 (MOL CM-2)	CNTMFRN (MOL CM-2)

Table 23. Program Output for Case 5 (Contd)

1.516E+00	2.021E+00	6.103E-03	0.		6.414E-03	5.306E+20	1.907E+20	5.387E+22

N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS	MEAN RH (PRCNT)
1.569E+00	2.212E+00	8.869E-01	8.989E-01	0.	0.	0.	84.39

FREQ CM-1	WAVELENGTH MICRONS	TOTAL TRANS	H2O TRANS	CO2+ TRANS	OZONE TRANS	N2 CONT TRANS	H2O CONT TRANS	MOL SCAT TRANS	AEROSOL TRANS	HNC3 TRANS	AEROSOL ABS	INTEGRATED ABSORPTION
900.	11.111	.2988	.9563	1.0000	1.0000	1.0000	.8078	1.0000	.3968	1.0000	.3812	1.753
905.	11.050	.2962	.9524	.9989	1.0000	1.0000	.8111	1.0000	.3838	1.0000	.3799	5.272
910.	10.989	.2943	.9511	.9983	1.0000	1.0000	.8145	1.0000	.3805	1.0000	.3784	8.801
915.	10.929	.2910	.9505	.9971	1.0000	1.0000	.8176	1.0000	.3755	1.0000	.3763	12.346
920.	10.870	.2888	.9531	.9957	1.0000	1.0000	.8208	1.0000	.3707	1.0000	.3742	15.902
925.	10.811	.2911	.9722	.9930	1.0000	1.0000	.8237	1.0000	.3660	1.0000	.3720	19.446
930.	10.753	.2882	.9745	.9899	1.0000	1.0000	.8257	1.0000	.3615	1.0000	.3700	23.005
935.	10.695	.2849	.9765	.9855	1.0000	1.0000	.8234	1.0000	.3570	1.0000	.3679	26.581
940.	10.638	.2806	.9730	.9829	1.0000	1.0000	.8322	1.0000	.3526	1.0000	.3658	30.177
945.	10.582	.2751	.9636	.9810	1.0000	1.0000	.8348	1.0000	.3486	1.0000	.3640	33.802
950.	10.526	.2723	.9576	.9800	.9998	1.0000	.8374	1.0000	.3465	1.0000	.3631	37.440
955.	10.471	.2700	.9524	.9805	.9996	1.0000	.8398	1.0000	.3444	1.0000	.3623	41.090
960.	10.417	.2685	.9505	.9803	.9993	1.0000	.8423	1.0000	.3423	1.0000	.3614	44.748
965.	10.363	.2672	.9498	.9800	.9987	1.0000	.8445	1.0000	.3403	1.0000	.3606	48.412
970.	10.309	.2651	.9490	.9770	.9981	1.0000	.8468	1.0000	.3383	1.0000	.3598	52.087
975.	10.256	.2645	.9511	.9770	.9970	1.0000	.8489	1.0000	.3363	1.0000	.3590	55.764
980.	10.204	.2660	.9583	.9805	.9948	1.0000	.8511	1.0000	.3344	1.0000	.3582	59.434
985.	10.152	.2683	.9676	.9858	.9918	1.0000	.8530	1.0000	.3325	1.0000	.3574	63.092
990.	10.101	.2690	.9742	.9923	.9845	1.0000	.8550	1.0000	.3306	1.0000	.3566	66.747
995.	10.050	.2646	.9625	.9967	.9791	1.0000	.8569	1.0000	.3287	1.0000	.3558	70.424
1000.	10.000	.2587	.9511	.9984	.9704	1.0000	.8587	1.0000	.3269	1.0000	.3551	74.131
1005.	9.950	.2550	.9451	.9992	.9605	1.0000	.8604	1.0000	.3267	1.0000	.3555	77.856
1010.	9.901	.2500	.9358	.9990	.9504	1.0000	.8622	1.0000	.3264	1.0000	.3560	81.606
1015.	9.852	.2415	.9249	.9981	.9401	1.0000	.8638	1.0000	.3261	1.0000	.3564	85.383
1020.	9.804	.2442	.9330	.9965	.9313	1.0000	.8654	1.0000	.3259	1.0000	.3568	89.162
1025.	9.756	.2425	.9311	.9939	.9283	1.0000	.8668	1.0000	.3256	1.0000	.3573	92.950
1030.	9.709	.2418	.9339	.9913	.9246	1.0000	.8683	1.0000	.3254	1.0000	.3577	96.741
1035.	9.662	.2357	.9420	.9858	.8976	1.0000	.8696	1.0000	.3251	1.0000	.3581	100.562
1040.	9.615	.2390	.9459	.9822	.9091	1.0000	.8709	1.0000	.3249	1.0000	.3585	104.367
1045.	9.569	.2493	.9474	.9770	.9513	1.0000	.8722	1.0000	.3246	1.0000	.3589	108.121
1050.	9.524	.2381	.9420	.9751	.9150	1.0000	.8734	1.0000	.3244	1.0000	.3593	111.930
1055.	9.479	.2339	.9369	.9731	.9052	1.0000	.8745	1.0000	.3242	1.0000	.3597	115.760
1060.	9.434	.2348	.9258	.9728	.9193	1.0000	.8757	1.0000	.3239	1.0000	.3601	119.586
1065.	9.390	.2391	.9214	.9716	.9412	1.0000	.8766	1.0000	.3237	1.0000	.3605	123.391
1070.	9.346	.2467	.9267	.9684	.9683	1.0000	.8775	1.0000	.3235	1.0000	.3609	127.157
1075.	9.302	.2538	.9284	.9678	.9948	1.0000	.8783	1.0000	.3232	1.0000	.3613	130.889
1080.	9.259	.2583	.9412	.9712	.9970	1.0000	.8790	1.0000	.3230	1.0000	.3617	134.595
1085.	9.217	.2610	.9412	.9793	.9973	1.0000	.8797	1.0000	.3228	1.0000	.3621	138.290
1090.	9.174	.2606	.9330	.9846	.9974	1.0000	.8803	1.0000	.3231	1.0000	.3617	141.987
1095.	9.132	.2605	.9223	.9927	.9974	1.0000	.8808	1.0000	.3239	1.0000	.3608	145.684
1100.	9.091	.2570	.9037	.9966	.9975	1.0000	.8813	1.0000	.3245	1.0000	.3599	149.399
1105.	9.050	.2539	.8885	.9990	.9974	1.0000	.8815	1.0000	.3253	1.0000	.3591	153.129

Table 23. Program Output for Case 5 (Contd)

1110.	9.009	.2534	.8846	.9995	.9973	1.0000	.8817	1.0000	.3260	1.0000	.3582	156.862
1115.	8.969	.2567	.8938	.9998	.9971	1.0000	.8819	1.0000	.3266	1.0000	.3577	160.579
1120.	8.929	.2599	.9037	.9994	.9970	1.0000	.8821	1.0000	.3272	1.000C	.3573	164.279
1125.	8.889	.2637	.9161	.9986	.9970	1.0000	.8821	1.0000	.3278	1.0C00	.3570	167.961
1130.	8.850	.2664	.9249	.9973	.9970	1.0000	.8821	1.0000	.3284	1.0000	.3566	171.629
1135.	8.811	.2631	.9139	.9949	.9974	1.0000	.8818	1.0000	.3290	1.0000	.3562	175.313
1140.	8.772	.2605	.9071	.99C5	.9980	1.0000	.8615	1.0000	.3295	1.0000	.3559	179.011
1145.	8.734	.2579	.9026	.9846	.9984	1.0000	.8806	1.0000	.3301	1.0000	.3555	180.866

INTEGRATED ABSORPTION FROM 900 TO 1145 CM-1 = 180.87 CM-1
AVERAGE TRANSMITTANCE = .2618

CARD 5 ***** 1

Table 24. Program Output for Case 6

```
                  ***** LOWTRAN 6 *****

CARD 1  *****    6    3    3    0    0    0    0    0     0.000    0.000

CARD 2  *****    1    0    0    0    0    0    0.000    0.000    0.000    0.000

CARD 3' *****     0.000     0.000    60.000   74          0.000

CARD 4  *****  6000.000  7500.000    20.000

PROGRAM WILL COMPUTE TRANSMITTED SOLAR IRRAD.

ATMOSPHERIC MODEL
        TEMPERATURE =   6     1962 U S STANDARD
        WATER VAPOR =   6     1962 U S STANDARD
        OZONE       =   6     1962 U S STANDARD

AEROSOL MODEL
        REGIME                 AEROSOL TYPE             PROFILE                    SEASON

        BOUNDARY LAYER (0-2 KM) RURAL                    23.0 KM VIS AT SEA LEVEL
        TROPOSPHERE   (2-10KM)  TROPOSPHERIC            TROPOSPHERIC              SPRING-SUMMER
        STRATOSPHERE (10-30KM)  BACKGROUND STRATO       BACKGROUND STRATO         SPRING-SUMMER
        UPPER ATMOS (30-100KM)  METEORIC DUST           NORMAL

SLANT PATH TO SPACE
        H1     =      0.000 KM
        HMIN   =      0.000 KM
        ANGLE  =     60.000 DEG

FREQUENCY RANGE
         V1 =       6000.0 CM-1  (       1.67 MICROMETERS)
         V2 =       7500.0 CM-1  (       1.33 MICROMETERS)
         DV =         20.0 CM-1


ATMOSPHERIC PROFILES
```

I	Z (KM)	P (MB)	T (K)	H2O (SCALED	CO2+ LOWTRAN	O3 UNITS)	N2	CNTMSLF (MOL/CM2 KM)	MOL SCAT (-)	N-1 (-)	O3 (UV) (ATM CM/KM)
1	0.00	1013.000	288.2	5.758E-01	9.285E-01	2.493E-03	7.378E-01	1.569E+20	9.475E-01	2.729E-04	2.520E-03
2	1.00	898.600	281.7	3.719E-01	7.771E-01	2.387E-03	6.010E-01	7.951E+19	8.601E-01	2.478E-04	2.520E-03
3	2.00	795.000	275.2	2.323E-01	6.474E-01	2.284E-03	4.870E-01	3.791E+19	7.788E-01	2.244E-04	2.520E-03
4	3.00	701.200	268.7	1.302E-01	5.371E-01	2.020E-03	3.927E-01	1.460E+19	7.035E-01	2.027E-04	2.333E-03
5	4.00	616.600	262.2	7.166E-02	4.435E-01	1.774E-03	3.150E-01	5.454E+18	6.340E-01	1.827E-04	2.147E-03
6	5.00	540.500	255.7	3.745E-02	3.646E-01	1.692E-03	2.513E-01	1.846E+18	5.698E-01	1.643E-04	2.147E-03
7	6.00	472.200	249.2	1.992E-02	2.982E-01	1.576E-03	1.994E-01	6.508E+17	5.108E-01	1.473E-04	2.100E-03
8	7.00	411.100	242.7	9.834E-03	2.427E-01	1.632E-03	1.572E-01	1.988E+17	4.566E-01	1.316E-04	2.287E-03
9	8.00	356.500	236.2	5.004E-03	1.963E-01	1.645E-03	1.232E-01	6.490E+16	4.069E-01	1.173E-04	2.427E-03
10	9.00	308.000	229.7	1.703E-03	1.579E-01	2.130E-03	9.586E-02	9.537E+15	3.615E-01	1.042E-04	3.313E-03
11	10.00	265.000	223.3	5.894E-04	1.262E-01	2.557E-03	7.403E-02	1.460E+15	3.199E-01	9.224E-05	4.200E-03
12	11.00	227.000	216.8	2.367E-04	1.002E-01	3.493E-03	5.678E-02	3.031E+14	2.823E-01	8.138E-05	6.067E-03
13	12.00	194.000	216.7	9.275E-05	7.619E-02	4.037E-03	4.150E-02	6.170E+13	2.413E-01	6.958E-05	7.467E-03
14	13.00	165.800	216.7	3.917E-05	5.788E-02	4.028E-03	3.031E-02	1.460E+13	2.063E-01	5.947E-05	7.933E-03
15	14.00	141.700	216.7	1.587E-05	4.397E-02	4.228E-03	2.214E-02	3.180E+12	1.763E-01	5.082E-05	8.867E-03

Table 24. Program Output for Case 6 (Contd)

16	15.00	121.100	216.7	1.181E-05	3.340E-02	4.388E-03	1.617E-02	2.337E+12	1.507E-01	4.344E-05	9.800E-03
17	16.00	103.500	216.7	8.687E-06	2.537E-02	4.710E-03	1.181E-02	1.677E+12	1.288E-01	3.712E-05	1.120E-02
18	17.00	88.500	216.7	6.432E-06	1.929E-02	5.161E-03	8.637E-03	1.219E+12	1.101E-01	3.174E-05	1.307E-02
19	18.00	75.650	216.7	4.726E-06	1.466E-02	5.540E-03	6.311E-03	8.726E+11	9.411E-02	2.713E-05	1.493E-02
20	19.00	64.670	216.7	4.104E-06	1.114E-02	5.691E-03	4.612E-03	8.726E+11	8.045E-02	2.320E-05	1.633E-02
21	20.00	55.290	216.7	3.564E-06	8.470E-03	5.803E-03	3.371E-03	8.726E+11	6.878E-02	1.983E-05	1.773E-02
22	21.00	47.290	217.6	3.371E-06	6.406E-03	5.447E-03	2.451E-03	1.038E+12	5.859E-02	1.689E-05	1.773E-02
23	22.00	40.470	218.6	3.163E-06	4.847E-03	5.248E-03	1.783E-03	1.219E+12	4.991E-02	1.439E-05	1.820E-02
24	23.00	34.670	219.6	3.015E-06	3.675E-03	4.802E-03	1.299E-03	1.464E+12	4.256E-02	1.227E-05	1.773E-02
25	24.00	29.720	220.6	2.803E-06	2.789E-03	4.274E-03	9.483E-04	1.677E+12	3.632E-02	1.047E-05	1.680E-02
26	25.00	25.490	221.6	2.636E-06	2.119E-03	3.792E-03	6.929E-04	1.963E+12	3.101E-02	8.940E-06	1.587E-02
27	30.00	11.970	226.5	7.612E-07	5.476E-04	1.642E-03	1.479E-04	6.508E+11	1.425E-02	4.108E-06	9.333E-03
28	35.00	5.746	236.5	1.624E-07	1.429E-04	6.674E-04	3.193E-05	1.154E+11	6.550E-03	1.888E-06	5.133E-03
29	40.00	2.871	250.4	3.549E-08	3.922E-05	2.227E-04	7.318E-06	2.023E+10	3.091E-03	8.912E-07	2.287E-03
30	45.00	1.491	264.2	9.176E-09	1.157E-05	5.881E-05	1.821E-06	4.615E+09	1.521E-03	4.386E-07	7.933E-04
31	50.00	.798	270.7	1.939E-09	3.747E-06	1.072E-05	5.027E-07	6.490E+08	7.945E-04	2.291E-07	1.867E-04
32	70.00	.055	219.7	2.406E-12	4.660E-08	8.259E-08	3.291E-09	1.014E+05	6.773E-05	1.953E-08	4.013E-06
33	100.00	.000	210.0	1.502E-16	5.420E-12	5.180E-12	1.046E-13	4.507E+00	3.861E-07	1.113E-10	2.007E-09

ATMOSPHERIC PROFILES

I	Z (KM)	P (MB)	T (K)	CNTMFRN MOL/CM2 KM	HNO3 ATM CM/KM	AEROSOL 1 (-)	AEROSOL 2 (-)	AEROSOL 3 (-)	AEROSOL 4 (-)	AER1*RH (-)	CIRRUS (-)	RH (PERCNT)
1	0.00	1013.000	288.2	2.010E+22	0.	1.580E-01	0.	0.	0.	7.250E+00	0.	4.599E+01
2	1.00	898.800	281.7	1.301E+22	0.	9.910E-02	0.	0.	0.	4.861E+00	0.	4.906E+01
3	2.00	795.000	275.2	8.143E+21	0.	6.210E-02	0.	0.	0.	3.230E+00	0.	5.201E+01
4	3.00	701.200	268.7	4.573E+21	0.	0.	3.460E-02	0.	0.	0.	0.	0.
5	4.00	616.600	262.2	2.521E+21	0.	0.	1.850E-02	0.	0.	0.	0.	0.
6	5.00	540.500	255.7	1.319E+21	0.	0.	9.310E-03	0.	0.	0.	0.	0.
7	6.00	472.200	249.2	7.025E+20	0.	0.	7.710E-03	0.	0.	0.	0.	0.
8	7.00	411.100	242.7	3.472E+20	0.	0.	6.230E-03	0.	0.	0.	0.	0.
9	8.00	356.500	236.2	1.768E+20	4.069E-15	0.	3.370E-03	0.	0.	0.	0.	0.
10	9.00	308.000	229.7	6.023E+19	3.615E-06	0.	1.820E-03	0.	0.	0.	0.	0.
11	10.00	265.000	223.3	2.096E+19	1.056E-05	0.	0.	1.140E-03	0.	0.	0.	0.
12	11.00	227.000	216.8	8.384E+18	2.258E-05	0.	0.	7.990E-04	0.	0.	0.	0.
13	12.00	194.000	216.7	3.235E+18	2.895E-05	0.	0.	6.410E-04	0.	0.	0.	0.
14	13.00	165.800	216.7	1.345E+18	2.888E-05	0.	0.	5.170E-04	0.	0.	0.	0.
15	14.00	141.700	216.7	5.364E+17	2.820E-05	0.	0.	4.420E-04	0.	0.	0.	0.
16	15.00	121.100	216.7	3.929E+17	2.712E-05	0.	0.	3.950E-04	0.	0.	0.	0.
17	16.00	103.500	216.7	2.845E+17	2.446E-05	0.	0.	3.820E-04	0.	0.	0.	0.
18	17.00	88.500	216.7	2.074E+17	2.202E-05	0.	0.	4.250E-04	0.	0.	0.	0.
19	18.00	75.650	216.7	1.500E+17	1.976E-05	0.	0.	5.200E-04	0.	0	0.	0.
20	19.00	64.670	216.7	1.282E+17	1.850E-05	0.	0.	5.810E-04	0.	0.	0.	0.
21	20.00	55.290	216.7	1.096E+17	2.063E-05	0.	0.	5.890E-04	0.	0.	0.	0.
22	21.00	47.290	217.6	1.019E+17	2.163E-05	0.	0.	5.020E-04	0.	0.	0.	0.
23	22.00	40.470	218.6	9.401E+16	2.096E-05	0.	0.	4.200E-04	0.	0.	0.	0.
24	23.00	34.670	219.6	8.788E+16	2.213E-05	0.	0.	3.000E-04	0.	0.	0.	0.
25	24.00	29.720	220.6	8.025E+16	2.179E-05	0.	0.	1.980E-04	0.	0.	0.	0.
26	25.00	25.490	221.6	7.414E+16	1.178E-05	0.	0.	1.310E-04	0.	0.	0.	0.
27	30.00	11.970	226.5	1.961E+16	3.704E-09	0.	0.	3.320E-05	0.	0.	0.	0.
28	35.00	5.746	236.5	3.796E+15	1.441E-07	0.	0.	0.	1.640E-05	0.	0.	0.
29	40.00	2.871	250.4	7.502E+14	3.091E-37	0.	0.	0.	7.990E-06	0.	0.	0.

Table 24. Program Output for Case 6 (Contd)

30	45.00	1.491	264.2	1.764E+14	0.	0.	0.	0.	4.010E-06	0.	0.	0.
31	50.00	.793	270.7	3.454E+13	0.	0.	0.	0.	2.100E-06	0.	0.	0.
32	70.00	.055	219.7	3.680E+10	0.	0.	0.	0.	1.600E-07	0.	0.	0.
33	100.00	.000	210.0	1.399E+06	0.	0.	0.	0.	9.310E-10	0.	0.	0.

CASE 3A: GIVEN H1,H2=SPACE,ANGLE

SLANT PATH PARAMETERS IN STANDARD FORM

H1	=	0.000 KM
H2	=	100.000 KM
ANGLE	=	60.000 DEG
PHI	=	121.474 DEG
HMIN	=	0.000 KM
LEN	=	0

CALCULATION OF THE REFRACTED PATH THROUGH THE ATMOSPHERE

I	ALTITUDE FROM (KM)	TO (KM)	THETA (DEG)	DRANGE (KM)	RANGE (KM)	DBETA (DEG)	BETA (DEG)	PHI (DEG)	DBEND (DEG)	BENDING (DEG)	PBAR (MB)	TBAR (K)	RHOBAR (GM CM-3)
	H1 TO H2												
1	0.000	1.000	60.000	2.000	2.000	.016	.016	120.013	.002	.002	955.683	284.99	1.17E-03
2	1.000	2.000	59.987	1.999	3.998	.016	.031	120.026	.002	.005	846.698	278.49	1.06E-03
3	2.000	3.000	59.974	1.998	5.996	.016	.047	120.040	.002	.007	747.913	271.99	9.57E-04
4	3.000	4.000	59.960	1.997	7.994	.016	.062	120.053	.002	.009	658.727	265.49	8.63E-04
5	4.000	5.000	59.947	1.996	9.990	.016	.078	120.067	.002	.011	578.391	258.99	7.77E-04
6	5.000	6.000	59.933	1.996	11.986	.016	.093	120.081	.002	.012	506.204	252.50	6.98E-04
7	6.000	7.000	59.919	1.995	13.980	.016	.109	120.095	.002	.014	441.516	246.00	6.24E-04
8	7.000	8.000	59.905	1.994	15.974	.015	.124	120.109	.001	.015	383.677	239.50	5.57E-04
9	8.000	9.000	59.891	1.993	17.967	.015	.140	120.123	.001	.017	332.137	233.00	4.96E-04
10	9.000	10.000	59.877	1.992	19.959	.015	.155	120.137	.001	.018	286.399	226.55	4.40E-04
11	10.000	11.000	59.863	1.991	21.951	.015	.171	120.152	.001	.019	245.907	220.19	3.89E-04
12	11.000	12.000	59.848	1.990	23.941	.015	.186	120.166	.001	.020	210.499	215.75	3.38E-04
13	12.000	13.000	59.834	1.990	25.331	.015	.202	120.180	.001	.021	179.900	216.70	2.89E-04
14	13.000	14.000	59.820	1.989	27.319	.015	.217	120.195	.001	.022	153.750	216.70	2.47E-04
15	14.000	15.000	59.805	1.988	29.907	.015	.232	120.210	.001	.023	131.400	216.70	2.11E-04
16	15.000	16.000	59.790	1.987	31.894	.015	.248	120.224	.001	.023	112.300	215.70	1.80E-04
17	16.000	17.000	59.776	1.986	33.880	.015	.263	120.239	.001	.024	96.000	216.70	1.54E-04
18	17.000	18.000	59.761	1.985	35.865	.015	.279	120.254	.000	.024	82.075	216.70	1.32E-04
19	18.000	19.000	59.746	1.984	37.850	.015	.294	120.269	.000	.025	70.160	216.70	1.13E-04
20	19.000	20.000	59.731	1.983	39.833	.015	.309	120.284	.000	.025	59.980	216.70	9.62E-05
21	20.000	21.000	59.716	1.983	41.816	.015	.325	120.299	.000	.025	51.293	217.14	8.21E-05
22	21.000	22.000	59.701	1.982	43.797	.015	.340	120.314	.000	.026	43.883	218.09	7.00E-05
23	22.000	23.000	59.686	1.981	45.778	.015	.355	120.330	.000	.026	37.572	219.09	5.96E-05
24	23.000	24.000	59.670	1.980	47.758	.015	.371	120.345	.000	.026	32.197	220.09	5.09E-05
25	24.000	25.000	59.655	1.979	49.737	.015	.386	120.360	.000	.026	27.607	221.09	4.34E-05
26	25.000	30.000	59.640	9.881	59.618	.076	.462	120.436	.000	.027	18.756	223.73	2.79E-05

Table 24. Program Output for Case 6 (Contd)

27	30.000	35.000	59.564	9.859	69.478	.076	.538	120.511	.000	.027	8.881	230.82	1.28E-05
28	35.000	40.000	59.489	9.837	79.315	.076	.614	120.587	.000	.027	4.322	242.52	5.95E-06
29	40.000	45.000	59.413	9.815	89.130	.075	.689	120.663	.000	.027	2.187	256.43	2.86E-06
30	45.000	50.000	59.337	9.793	98.923	.075	.765	120.738	.000	.027	1.146	267.09	1.45E-06
31	50.000	70.000	59.262	38.960	137.884	.298	1.062	121.036	.000	.027	.416	253.95	3.82E-07
32	70.000	100.000	58.964	57.820	195.704	.439	1.501	121.474	.000	.027	.028	217.86	1.69E-08

CUMULATIVE ABSORBER AMOUNTS FOR THE PATH FROM H1 TO Z

J	Z (KM)	TBAR (K)	H2O (SCALED LOWTRAN UNITS)	CO2+	O3	HNO3 (ATM CM)	O3 UV (ATM CM)	CNTMSLF1 (MOL CM-2)	CNTMSLF2 (MOL CM-2)	CNTMFRN (MOL CM-2)
1	1.000	284.99	9.327E-01	1.701E+00	4.878E-03	0.	5.039E-03	2.277E+20	6.962E+19	3.258E+22
2	2.000	278.49	1.526E+00	3.121E+00	9.546E-03	0.	1.008E-02	3.399E+20	1.242E+20	5.334E+22
3	3.000	271.99	1.878E+00	4.300E+00	1.384E-02	0.	1.492E-02	3.887E+20	1.568E+20	6.570E+22
4	4.000	265.49	2.074E+00	5.277E+00	1.762E-02	0.	1.939E-02	4.073E+20	1.725E+20	7.259E+22
5	5.000	258.99	2.179E+00	6.081E+00	2.108E-02	0.	2.368E-02	4.139E+20	1.791E+20	7.629E+22
6	6.000	252.50	2.234E+00	6.740E+00	2.434E-02	0.	2.792E-02	4.162E+20	1.814E+20	7.824E+22
7	7.000	246.00	2.263E+00	7.277E+00	2.754E-02	0.	3.229E-02	4.170E+20	1.822E+20	7.925E+22
8	8.000	239.50	2.277E+00	7.713E+00	3.081E-02	4.056E-35	3.699E-02	4.172E+20	1.824E+20	7.975E+22
9	9.000	233.00	2.283E+00	8.065E+00	3.457E-02	3.602E-06	4.271E-02	4.173E+20	1.825E+20	7.997E+22
10	10.000	226.55	2.285E+00	8.347E+00	3.924E-02	1.772E-05	5.019E-02	4.173E+20	1.825E+20	8.004E+22
11	11.000	220.10	2.286E+00	8.571E+00	4.526E-02	5.071E-05	6.042E-02	4.173E+20	1.825E+20	8.007E+22
12	12.000	216.75	2.286E+00	8.746E+00	5.276E-02	1.020E-04	7.386E-02	4.173E+20	1.825E+20	8.008E+22
13	13.000	216.70	2.287E+00	8.879E+00	6.078E-02	1.595E-04	8.920E-02	4.173E+20	1.825E+20	8.008E+22
14	14.000	216.70	2.287E+00	8.979E+00	6.899E-02	2.163E-04	1.059E-01	4.173E+20	1.825E+20	8.009E+22
15	15.000	216.70	2.287E+00	9.055E+00	7.755E-02	2.713E-04	1.245E-01	4.173E+20	1.825E+20	8.009E+22
16	16.000	216.70	2.287E+00	9.113E+00	8.659E-02	3.225E-04	1.453E-01	4.173E+20	1.825E+20	8.009E+22
17	17.000	216.70	2.287E+00	9.157E+00	9.640E-02	3.686E-04	1.694E-01	4.173E+20	1.825E+20	8.009E+22
18	18.000	216.70	2.287E+00	9.191E+00	1.070E-01	4.100E-04	1.972E-01	4.173E+20	1.825E+20	8.009E+22
19	19.000	216.70	2.287E+00	9.216E+00	1.182E-01	4.480E-04	2.282E-01	4.173E+20	1.825E+20	8.009E+22
20	20.000	216.70	2.287E+00	9.236E+00	1.296E-01	4.868E-04	2.620E-01	4.173E+20	1.825E+20	8.009E+22
21	21.000	217.14	2.287E+00	9.250E+00	1.407E-01	5.287E-04	2.972E-01	4.173E+20	1.825E+20	8.009E+22
22	22.000	218.09	2.287E+00	9.261E+00	1.513E-01	5.710E-04	3.328E-01	4.173E+20	1.825E+20	8.009E+22
23	23.000	219.09	2.287E+00	9.270E+00	1.613E-01	6.137E-04	3.684E-01	4.173E+20	1.825E+20	8.009E+22
24	24.000	220.09	2.287E+00	9.276E+00	1.702E-01	6.571E-04	4.025E-01	4.173E+20	1.825E+20	8.009E+22
25	25.000	221.09	2.287E+00	9.281E+00	1.782E-01	6.893E-04	4.319E-01	4.173E+20	1.825E+20	8.009E+22
26	30.000	223.73	2.287E+00	9.292E+00	2.036E-01	7.583E-04	5.565E-01	4.173E+20	1.825E+20	8.009E+22
27	35.000	230.82	2.287E+00	9.295E+00	2.143E-01	7.692E-04	6.258E-01	4.173E+20	1.825E+20	8.009E+22
28	40.000	242.52	2.287E+00	9.296E+00	2.182E-01	7.692E-04	6.604E-01	4.173E+20	1.825E+20	8.009E+22
29	45.000	256.43	2.287E+00	9.296E+00	2.194E-01	7.692E-04	6.743E-01	4.173E+20	1.825E+20	8.009E+22
30	50.000	267.09	2.287E+00	9.296E+00	2.197E-01	7.692E-04	6.784E-01	4.173E+20	1.825E+20	8.009E+22
31	70.000	253.95	2.287E+00	9.297E+00	2.198E-01	7.692E-04	6.802E-01	4.173E+20	1.825E+20	8.009E+22
32	100.000	217.86	2.287E+00	9.297E+00	2.198E-01	7.692E-04	6.803E-01	4.173E+20	1.825E+20	8.009E+22

J	Z (KM)	N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS
1	1.000	1.334E+00	1.806E+00	2.525E-01	0.	0.	0.	0.

Table 24. Program Output for Case 6 (Contd)

2	2.000	2.417E+00	3.442E+00	4.107E-01	0.	0.	0.	0.
3	3.000	3.293E+00	4.922E+00	4.728E-01	3.457E-02	0.	0.	0.
4	4.000	3.997E+00	6.256E+00	4.728E-01	8.592E-02	0.	0.	0.
5	5.000	4.559E+00	7.457E+00	4.728E-01	1.126E-01	0.	0.	0.
6	6.000	5.007E+00	8.534E+00	4.728E-01	1.296E-01	0.	0.	0.
7	7.000	5.361E+00	9.493E+00	4.728E-01	1.434E-01	0.	0.	0.
8	8.000	5.639E+00	1.036E+01	4.728E-01	1.527E-01	0.	0.	0.
9	9.000	5.856E+00	1.112E+01	4.728E-01	1.577E-01	0.	0.	0.
10	10.000	6.025E+00	1.180E+01	4.728E-01	1.595E-01	1.136E-03	0.	0.
11	11.000	6.154E+00	1.240E+01	4.728E-01	1.595E-01	3.046E-03	0.	0.
12	12.000	6.251E+00	1.292E+01	4.728E-01	1.595E-01	4.473E-03	0.	0.
13	13.000	6.322E+00	1.336E+01	4.728E-01	1.595E-01	5.621E-03	0.	0.
14	14.000	6.374E+00	1.374E+01	4.728E-01	1.595E-01	6.573E-03	0.	0.
15	15.000	6.412E+00	1.407E+01	4.729E-01	1.595E-01	7.404E-03	0.	0.
16	16.000	6.439E+00	1.434E+01	4.728E-01	1.595E-01	8.176E-03	0.	0.
17	17.000	6.459E+00	1.458E+01	4.728E-01	1.595E-01	8.977E-03	0.	0.
18	18.000	6.474E+00	1.478E+01	4.728E-01	1.595E-01	9.915E-03	0.	0.
19	19.000	6.485E+00	1.496E+01	4.728E-01	1.595E-01	1.101E-02	0.	0.
20	20.000	6.493E+00	1.510E+01	4.728E-01	1.595E-01	1.217E-02	0.	0.
21	21.000	6.498E+00	1.523E+01	4.728E-01	1.595E-01	1.325E-02	0.	0.
22	22.000	6.503E+00	1.534E+01	4.728E-01	1.595E-01	1.416E-02	0.	0.
23	23.000	6.506E+00	1.543E+01	4.728E-01	1.595E-01	1.486E-02	0.	0.
24	24.000	6.508E+00	1.551E+01	4.728E-01	1.595E-01	1.535E-02	0.	0.
25	25.000	6.503E+00	1.537E+01	4.728E-01	1.595E-01	1.567E-02	0.	0.
26	30.000	6.513E+00	1.579E+01	4.728E-01	1.595E-01	1.638E-02	0.	0.
27	35.000	6.514E+00	1.588E+01	4.728E-01	1.595E-01	1.654E-02	8.082E-05	0.
28	40.000	6.514E+00	1.593E+01	4.728E-01	1.595E-01	1.654E-02	1.959E-04	0.
29	45.000	6.514E+00	1.595E+01	4.728E-01	1.595E-01	1.654E-02	2.526E-04	0.
30	50.000	6.514E+00	1.596E+01	4.728E-01	1.595E-01	1.654E-02	2.815E-04	0.
31	70.000	6.514E+00	1.597E+01	4.728E-01	1.595E-01	1.654E-02	3.109E-04	0.
32	100.000	6.514E+00	1.597E+01	4.728E-01	1.595E-01	1.654E-02	3.127E-04	0.

SUMMARY OF THE GEOMETRY CALCULATION

```
H1      =     0.000 KM
H2      =   100.000 KM
ANGLE   =    60.000 DEG
RANGE   =   195.704 KM
BETA    =     1.501 DEG
PHI     =   121.474 DEG
HMIN    =     0.000 KM
BENDING =      .027 DEG
LEN     =         0
```

EQUIVALENT SEA LEVEL TOTAL ABSORBER AMOUNTS

H2O	CO2+	O3	HNO3	O3 UV	CNTMSLF1	CNTMSLF2	CNTMFRN
(SCALED LOWTRAN UNITS)			(ATM CM)	(ATM CM)	(MOL CM-2)	(MOL CM-2)	(MOL CM-2)

Table 24. Program Output for Case 6 (Contd)

2.287E+00	9.297E+00	2.198E-01	7.692E-04	6.803E-01	4.173E+20	1.625E+20	8.009E+22
N2 CONT	MOL SCAT	AER 1	AER 2	AER 3	AER 4	CIRRUS	MEAN RH (PRCNT)
6.514E+00	1.597E+01	4.728E-01	1.595E-01	1.654E-02	3.127E-04	0.	48.97

IRRADIANCE (WATTS/CM2-XXXX)

FREQ (CM-1)	WAVLEN (MICRN)	TRANSMITTED (CM-1)	TRANSMITTED (MICRN)	SOLAR (CM-1)	SOLAR (MICRN)	INTEGRATED TRANS.	INTEGRATED SOLAR	TOTAL TRANS
6000.	1.667	5.07E-06	1.83E-02	6.00E-06	2.16E-02	5.07E-05	6.00E-05	.8452
6020.	1.661	5.10E-06	1.85E-02	6.02E-06	2.18E-02	1.53E-04	1.80E-04	.8469
6040.	1.656	5.12E-06	1.87E-02	6.05E-06	2.21E-02	2.55E-04	3.01E-04	.8467
6060.	1.650	5.11E-06	1.88E-02	6.07E-06	2.23E-02	3.57E-04	4.23E-04	.8416
6080.	1.645	5.14E-06	1.90E-02	6.10E-06	2.25E-02	4.60E-04	5.45E-04	.8435
6100.	1.639	5.17E-06	1.92E-02	6.12E-06	2.28E-02	5.64E-04	6.67E-04	.8447
6120.	1.634	5.23E-06	1.96E-02	6.14E-06	2.30E-02	6.68E-04	7.90E-04	.8516
6140.	1.629	5.25E-06	1.98E-02	6.16E-06	2.32E-02	7.73E-04	9.13E-04	.8513
6160.	1.623	5.26E-06	1.99E-02	6.19E-06	2.35E-02	8.78E-04	1.04E-03	.8496
6180.	1.618	5.19E-06	1.98E-02	6.21E-06	2.37E-02	9.82E-04	1.16E-03	.8355
6200.	1.613	5.00E-06	1.92E-02	6.23E-06	2.39E-02	1.08E-03	1.29E-03	.8024
6220.	1.608	4.82E-06	1.86E-02	6.24E-06	2.42E-02	1.18E-03	1.41E-03	.7719
6240.	1.603	4.68E-06	1.82E-02	6.26E-06	2.44E-02	1.27E-03	1.54E-03	.7479
6260.	1.597	5.27E-06	2.06E-02	6.28E-06	2.46E-02	1.38E-03	1.66E-03	.8384
6280.	1.592	5.34E-06	2.11E-02	6.30E-06	2.48E-02	1.48E-03	1.79E-03	.8477
6300.	1.587	5.32E-06	2.11E-02	6.31E-06	2.51E-02	1.59E-03	1.91E-03	.8431
6320.	1.582	5.06E-06	2.02E-02	6.33E-06	2.53E-02	1.69E-03	2.04E-03	.7993
6340.	1.577	4.87E-06	1.96E-02	6.34E-06	2.55E-02	1.79E-03	2.17E-03	.7680
6360.	1.572	4.65E-06	1.88E-02	6.36E-06	2.57E-02	1.88E-03	2.29E-03	.7308
6380.	1.567	5.30E-06	2.16E-02	6.37E-06	2.59E-02	1.99E-03	2.42E-03	.8314
6400.	1.563	5.39E-06	2.21E-02	6.38E-06	2.62E-02	2.10E-03	2.55E-03	.8449
6420.	1.559	5.40E-06	2.23E-02	6.40E-06	2.64E-02	2.20E-03	2.68E-03	.8444
6440.	1.553	5.41E-06	2.24E-02	6.41E-06	2.66E-02	2.31E-03	2.81E-03	.8439
6460.	1.548	5.41E-06	2.26E-02	6.42E-06	2.68E-02	2.42E-03	2.93E-03	.8431
6480.	1.543	5.37E-06	2.26E-02	6.43E-06	2.70E-02	2.53E-03	3.06E-03	.8360
6500.	1.538	5.36E-06	2.27E-02	6.43E-06	2.72E-02	2.63E-03	3.19E-03	.8337
6520.	1.534	5.31E-06	2.26E-02	6.44E-06	2.74E-02	2.74E-03	3.32E-03	.8248
6540.	1.529	5.38E-06	2.30E-02	6.45E-06	2.76E-02	2.85E-03	3.45E-03	.8342
6560.	1.524	5.29E-06	2.28E-02	6.45E-06	2.78E-02	2.95E-03	3.58E-03	.8202
6580.	1.520	5.10E-06	2.21E-02	6.46E-06	2.80E-02	3.06E-03	3.71E-03	.7892
6600.	1.515	4.87E-06	2.12E-02	6.47E-06	2.82E-02	3.15E-03	3.84E-03	.7527
6620.	1.511	4.46E-06	1.95E-02	6.47E-06	2.84E-02	3.24E-03	3.97E-03	.6890
6640.	1.506	3.72E-06	1.64E-02	6.47E-06	2.85E-02	3.32E-03	4.10E-03	.5739
6660.	1.502	3.53E-06	1.56E-02	6.48E-06	2.87E-02	3.39E-03	4.22E-03	.5445
6680.	1.497	2.91E-06	1.30E-02	6.49E-06	2.89E-02	3.45E-03	4.35E-03	.4482
6700.	1.493	3.05E-06	1.37E-02	6.50E-06	2.92E-02	3.51E-03	4.48E-03	.4693
6720.	1.488	1.88E-06	8.47E-03	6.50E-06	2.94E-02	3.54E-03	4.61E-03	.2883
6740.	1.484	2.11E-06	9.58E-03	6.51E-06	2.96E-02	3.59E-03	4.74E-03	.3237
6760.	1.479	1.05E-06	4.79E-03	6.52E-06	2.98E-02	3.61E-03	4.86E-03	.1607
6780.	1.475	1.33E-06	6.10E-03	6.53E-06	3.00E-02	3.63E-03	5.01E-03	.2033
6800.	1.471	5.37E-07	2.48E-03	6.53E-06	3.02E-02	3.65E-03	5.14E-03	.0822
6820.	1.466	9.90E-07	4.60E-03	6.54E-06	3.04E-02	3.66E-03	5.27E-03	.1513

Table 24. Program Output for Case 6 (Contd)

6840.	1.462	1.05E-06	4.93E-03	6.55E-06	3.06E-02	3.69E-03	5.40E-03	.1809
6860.	1.458	2.40E-06	1.13E-02	6.55E-06	3.08E-02	3.73E-03	5.53E-03	.3661
6880.	1.453	1.59E-06	7.50E-03	6.56E-06	3.10E-02	3.77E-03	5.66E-03	.2418
6900.	1.449	4.93E-07	2.35E-03	6.56E-06	3.12E-02	3.78E-03	5.79E-03	.0751
6920.	1.445	2.29E-07	1.10E-03	6.57E-06	3.14E-02	3.78E-03	5.92E-03	.0349
6940.	1.441	3.08E-07	1.48E-03	6.57E-06	3.17E-02	3.79E-03	6.05E-03	.0468
6960.	1.437	4.40E-07	2.13E-03	6.58E-06	3.19E-02	3.79E-03	6.19E-03	.0670
6980.	1.433	8.24E-08	4.01E-04	6.58E-06	3.21E-02	3.80E-03	6.32E-03	.0125

IRRADIANCE (WATTS/CM2-XXXX)

FREQ	WAVLEN	TRANSMITTED		SOLAR		INTEGRATED		TOTAL
(CM-1)	(MICRN)	(CM-1)	(MICRN)	(CM-1)	(MICRN)	TRANS.	SOLAR	TRANS
7000.	1.429	2.38E-07	1.17E-03	6.59E-06	3.23E-02	3.80E-03	6.45E-03	.0362
7020.	1.425	6.16E-08	3.03E-04	6.59E-06	3.25E-02	3.80E-03	6.58E-03	.0093
7040.	1.420	8.58E-08	4.25E-04	6.59E-06	3.27E-02	3.80E-03	6.71E-03	.0130
7060.	1.416	5.17E-08	2.58E-04	6.60E-06	3.29E-02	3.81E-03	6.84E-03	.0078
7080.	1.412	1.79E-08	8.95E-05	6.60E-06	3.31E-02	3.81E-03	6.98E-03	.0027
7100.	1.408	0.	0.	6.60E-06	3.33E-02	3.81E-03	7.11E-03	0.0000
7120.	1.404	2.08E-09	1.05E-05	6.60E-06	3.35E-02	3.81E-03	7.24E-03	.0003
7140.	1.401	0.	0.	6.60E-06	3.37E-02	3.81E-03	7.37E-03	0.0000
7160.	1.397	0.	0.	6.60E-06	3.38E-02	3.81E-03	7.50E-03	0.0000
7180.	1.393	6.18E-10	3.19E-06	6.60E-06	3.40E-02	3.81E-03	7.64E-03	.0001
7200.	1.389	5.62E-10	2.91E-06	6.59E-06	3.42E-02	3.81E-03	7.77E-03	.0001
7220.	1.385	0.	0.	6.59E-06	3.43E-02	3.81E-03	7.90E-03	0.0000
7240.	1.381	0.	0.	6.58E-06	3.45E-02	3.81E-03	8.03E-03	0.0000
7260.	1.377	3.15E-10	1.66E-06	6.57E-06	3.46E-02	3.81E-03	8.16E-03	.0000
7280.	1.374	2.19E-10	1.16E-06	6.57E-06	3.48E-02	3.81E-03	8.29E-03	.0000
7300.	1.370	0.	0.	6.56E-06	3.50E-02	3.81E-03	8.43E-03	0.0000
7320.	1.366	0.	0.	6.55E-06	3.51E-02	3.81E-03	8.56E-03	0.0000
7340.	1.362	0.	0.	6.55E-06	3.53E-02	3.81E-03	8.69E-03	0.0000
7360.	1.359	0.	0.	6.54E-06	3.54E-02	3.81E-03	8.82E-03	0.0000
7380.	1.355	0.	0.	6.53E-06	3.56E-02	3.81E-03	8.95E-03	0.0000
7400.	1.351	1.11E-08	6.06E-05	6.53E-06	3.57E-02	3.81E-03	9.08E-03	.0017
7420.	1.348	1.04E-07	5.75E-04	6.53E-06	3.60E-02	3.81E-03	9.21E-03	.0160
7440.	1.344	8.74E-07	4.84E-03	6.55E-06	3.63E-02	3.83E-03	9.34E-03	.1335
7460.	1.340	1.75E-06	9.76E-03	6.57E-06	3.65E-02	3.86E-03	9.47E-03	.2671
7480.	1.337	2.13E-06	1.19E-02	6.58E-06	3.68E-02	3.90E-03	9.60E-03	.3229
7500.	1.333	2.44E-06	1.37E-02	6.60E-06	3.71E-02	3.93E-03	9.67E-03	.3703

INTEGRATED ABSORPTION FROM 6000 TO 7500 CM-1 = 879.65 CM-1
AVERAGE TRANSMITTANCE = .4136

INTEGRATED RADIANCE = 3.928E-03 WATTS CM-2 STER-1
MINIMUM RADIANCE = 0. WATTS CM-2 STER-1 (CM-1)-1 AT 7380.0 CM-1
MAXIMUM RADIANCE = 5.411E-06 WATTS CM-2 STER-1 (CM-1)-1 AT 6460.0 CM-1

CARD 5 ***** 0

Table 25. Tape 7 Output

```
  6    2    2    0    0    0    0    0   300.000     .050
  1    1    1    0    0    0   23.000     0.000     0.000     0.000
 -99.000   -99.000      -99
 -99.000   -99.000   -99.000
 331952 U S STANDARD
 100.000     0.000   158.706   107.456      .351     0.000    0
  2    2    1    0
  45.000    60.000     0.000     0.000     0.000     0.000     0.000     0.000
4000.000  4500.000    10.000
  1
1.0000  1.0000
4000.   2.500 5.72E-11 9.15E-08 2.41E-10 3.85E-07 6.29E-11 1.01E-07 3.61E-10 5.77E-07 1.80E-09   .0707   .0044   .0239
4010.   2.494 5.77E-11 9.29E-08 2.59E-10 4.16E-07 9.00E-11 1.45E-07 4.07E-10 6.54E-07 5.87E-09   .0800   .0063   .0294
4020.   2.488 6.50E-11 1.05E-07 3.10E-10 5.02E-07 1.69E-10 2.74E-07 5.45E-10 8.80E-07 1.13E-08   .1075   .0118   .0462
4030.   2.481 8.11E-11 1.32E-07 4.19E-10 6.80E-07 4.34E-10 7.04E-07 9.34E-10 1.52E-06 2.07E-08   .1659   .0301   .0849
4040.   2.475 9.92E-11 1.62E-07 5.58E-10 9.11E-07 9.07E-10 1.48E-06 1.56E-09 2.55E-06 3.63E-08   .2405   .0628   .1420
4050.   2.469 1.16E-10 1.91E-07 7.11E-10 1.17E-06 1.58E-09 2.59E-06 2.40E-09 3.94E-06 6.03E-08   .3212   .1088   .2098
4060.   2.463 1.39E-10 2.30E-07 9.35E-10 1.54E-06 2.76E-09 4.54E-06 3.83E-09 6.31E-06 9.86E-08   .4345   .1896   .3155
4070.   2.457 1.30E-10 2.16E-07 9.15E-10 1.52E-06 2.66E-09 4.40E-06 3.70E-09 6.13E-06 1.36E-07   .4199   .1825   .3044
4080.   2.451 9.65E-11 1.61E-07 6.81E-10 1.13E-06 1.47E-09 2.45E-06 2.25E-09 3.74E-06 1.58E-07   .2979   .1009   .1932
4090.   2.445 1.13E-10 1.89E-07 8.67E-10 1.45E-06 2.43E-09 4.06E-06 3.41E-09 5.70E-06 1.92E-07   .3891   .1663   .2797
4100.   2.439 1.23E-10 2.06E-07 1.01E-09 1.71E-06 3.29E-09 5.52E-06 4.42E-09 7.44E-06 2.36E-07   .4609   .2245   .3473
4110.   2.433 1.21E-10 2.04E-07 1.05E-09 1.78E-06 3.51E-09 5.93E-06 4.68E-09 7.91E-06 2.83E-07   .4753   .2395   .3624
4120.   2.427 1.45E-10 2.46E-07 1.39E-09 2.36E-06 5.75E-09 9.76E-06 7.28E-09 1.24E-05 3.56E-07   .6368   .3914   .5303
4130.   2.421 1.10E-10 1.87E-07 1.05E-09 1.79E-06 3.49E-09 5.96E-06 4.65E-09 7.94E-06 4.03E-07   .4687   .2373   .3577
4140.   2.415 1.02E-10 1.75E-07 1.02E-09 1.75E-06 3.29E-09 5.65E-06 4.41E-09 7.57E-06 4.47E-07   .4493   .2235   .3411
4150.   2.410 1.14E-10 1.96E-07 1.23E-09 2.11E-06 4.63E-09 7.97E-06 5.97E-09 1.03E-05 5.06E-07   .5492   .3136   .4381
4160.   2.404 1.22E-10 2.12E-07 1.42E-09 2.47E-06 5.99E-09 1.04E-05 7.54E-09 1.31E-05 5.82E-07   .6374   .4053   .5368
4170.   2.398 1.25E-10 2.18E-07 1.55E-09 2.70E-06 6.98E-09 1.21E-05 8.66E-09 1.51E-05 6.68E-07   .6917   .4693   .5962
4180.   2.392 1.18E-10 2.06E-07 1.52E-09 2.66E-06 6.68E-09 1.17E-05 8.32E-09 1.45E-05 7.52E-07   .6723   .4487   .5754
4190.   2.387 1.09E-10 1.92E-07 1.46E-09 2.57E-06 6.22E-09 1.09E-05 7.79E-09 1.37E-05 8.30E-07   .6428   .4172   .5446
4200.   2.381 1.04E-10 1.84E-07 1.46E-09 2.58E-06 6.16E-09 1.09E-05 7.72E-09 1.36E-05 9.07E-07   .6382   .4125   .5391
4210.   2.375 1.05E-10 1.87E-07 1.57E-09 2.78E-06 6.96E-09 1.23E-05 8.63E-09 1.53E-05 9.93E-07   .6830   .4655   .5891
4220.   2.370 1.07E-10 1.90E-07 1.69E-09 3.01E-06 7.92E-09 1.41E-05 9.71E-09 1.73E-05 1.09E-06   .7330   .5292   .6489
4230.   2.364 1.07E-10 1.91E-07 1.78E-09 3.19E-06 8.65E-09 1.55E-05 1.05E-08 1.89E-05 1.20E-06   .7682   .5775   .6928
4240.   2.358 1.06E-10 1.90E-07 1.87E-09 3.37E-06 9.46E-09 1.70E-05 1.14E-08 2.06E-05 1.31E-06   .8030   .6308   .7355
4250.   2.353 9.67E-11 1.75E-07 1.76E-09 3.19E-06 8.42E-09 1.52E-05 1.03E-08 1.86E-05 1.41E-06   .7546   .5608   .6760
4260.   2.347 9.48E-11 1.72E-07 1.82E-09 3.31E-06 8.87E-09 1.61E-05 1.08E-08 1.96E-05 1.52E-06   .7752   .5903   .7021
4270.   2.342 9.46E-11 1.73E-07 1.92E-09 3.51E-06 9.73E-09 1.77E-05 1.17E-08 2.14E-05 1.64E-06   .8130   .6469   .7483
4280.   2.336 9.23E-11 1.69E-07 1.97E-09 3.61E-06 1.01E-08 1.85E-05 1.22E-08 2.23E-05 1.76E-06   .8290   .6705   .7677
4290.   2.331 9.14E-11 1.68E-07 2.06E-09 3.79E-06 1.08E-08 1.99E-05 1.30E-08 2.39E-05 1.89E-06   .8614   .7180   .8078
4300.   2.326 8.47E-11 1.57E-07 1.98E-09 3.66E-06 1.00E-08 1.86E-05 1.21E-08 2.24E-05 2.01E-06   .8258   .6664   .7641
4310.   2.320 8.24E-11 1.53E-07 2.02E-09 3.75E-06 1.04E-08 1.93E-05 1.25E-08 2.32E-05 2.14E-06   .8393   .6869   .7815
4320.   2.315 8.25E-11 1.54E-07 2.14E-09 3.99E-06 1.14E-08 2.12E-05 1.36E-08 2.53E-05 2.27E-06   .8837   .7517   .8363
4330.   2.309 8.03E-11 1.50E-07 2.18E-09 4.09E-06 1.17E-08 2.19E-05 1.39E-08 2.61E-05 2.41E-06   .8981   .7722   .8533
4340.   2.304 7.74E-11 1.46E-07 2.20E-09 4.15E-06 1.18E-08 2.22E-05 1.41E-08 2.65E-05 2.55E-06   .9028   .7798   .8598
4350.   2.299 7.43E-11 1.41E-07 2.22E-09 4.20E-06 1.19E-08 2.25E-05 1.42E-08 2.68E-05 2.69E-06   .9030   .7802   .8600
4360.   2.294 7.17E-11 1.36E-07 2.25E-09 4.27E-06 1.20E-08 2.29E-05 1.43E-08 2.73E-05 2.84E-06   .9092   .7883   .8677
4370.   2.288 6.91E-11 1.32E-07 2.27E-09 4.34E-06 1.22E-08 2.33E-05 1.45E-08 2.78E-05 2.98E-06   .9153   .7972   .8744
4380.   2.283 6.66E-11 1.28E-07 2.30E-09 4.41E-06 1.23E-08 2.37E-05 1.47E-08 2.82E-05 3.13E-06   .9200   .8053   .8811
4390.   2.278 6.41E-11 1.24E-07 2.32E-09 4.47E-06 1.25E-08 2.40E-05 1.48E-08 2.86E-05 3.28E-06   .9235   .8107   .8850
4400.   2.273 6.17E-11 1.19E-07 2.34E-09 4.53E-06 1.26E-08 2.44E-05 1.50E-08 2.90E-05 3.43E-06   .9269   .8175   .8898
4410.   2.268 5.94E-11 1.16E-07 2.36E-09 4.59E-06 1.27E-08 2.47E-05 1.51E-08 2.94E-05 3.58E-06   .9307   .8230   .8934
4420.   2.262 5.71E-11 1.12E-07 2.38E-09 4.64E-06 1.28E-08 2.49E-05 1.52E-08 2.97E-05 3.73E-06   .9320   .8250   .8950
```

Table 25. Tape 7 Output (Contd)

```
 4430.    2.257 5.48E-11 1.07E-07 2.39E-09 4.68E-06 1.28E-08 2.51E-05 1.52E-08 2.99E-05 3.88E-06   .9320   .8242   .8947
 4440.    2.252 5.27E-11 1.04E-07 2.41E-09 4.75E-06 1.29E-08 2.55E-05 1.54E-08 3.03E-05 4.04E-06   .9352   .8306   .9003
 4450.    2.247 5.07E-11 1.00E-07 2.43E-09 4.82E-06 1.30E-08 2.58E-05 1.55E-08 3.07E-05 4.19E-06   .9381   .8364   .9055
 4460.    2.242 4.87E-11 9.69E-08 2.45E-09 4.88E-06 1.31E-08 2.60E-05 1.56E-08 3.10E-05 4.35E-06   .9386   .8374   .9065
 4470.    2.237 4.66E-11 9.32E-08 2.46E-09 4.91E-06 1.30E-08 2.61E-05 1.56E-08 3.11E-05 4.50E-06   .9366   .8340   .9034
 4480.    2.232 4.47E-11 8.96E-08 2.47E-09 4.95E-06 1.30E-08 2.61E-05 1.55E-08 3.11E-05 4.66E-06   .9339   .8297   .8998
 4490.    2.227 4.26E-11 8.59E-08 2.46E-09 4.97E-06 1.29E-08 2.60E-05 1.54E-08 3.10E-05 4.81E-06   .9279   .8199   .8926
 4500.    2.222 4.06E-11 8.22E-08 2.45E-09 4.96E-06 1.26E-08 2.56E-05 1.51E-08 3.07E-05 4.89E-06   .9190   .8041   .8800
-9999.
    1    2    0    0    0    0    0    0      0.000      0.000
    1    1    1    0    1    0   23.000      0.000      0.000      0.000
    1.000     11.000          0
  -99.000    -99.000    -99.000
 33TROPICAL MODEL
    7.000     12.000     91.670    545.094      4.890      0.000    1
  -99  -99  -99  -99
  -99.000    -99.000    -99.000    -99.000    -99.000    -99.000    -99.000    -99.000
  900.000   1145.000      5.000
    1
 1.0000    .0437
  900.  11.111   .0022   .7466  1.0000  1.0000  1.0000   .0727  1.0000   .9410   .9875   .0563     2.4945
  905.  11.050   .0022   .7306   .9656  1.0000  1.0000   .0763  1.0000   .9410   .9910   .0562     7.4835
  910.  10.989   .0023   .7245   .9527  1.0000  1.0000   .0801  1.0000   .9407   .9926   .0564    12.4722
  915.  10.929   .0023   .7215   .9297  1.0000  1.0000   .0838  1.0000   .9394   .9941   .0577    17.4607
  920.  10.870   .0024   .7336   .9076   .9999  1.0000   .0877  1.0000   .9381   .9966   .0589    22.4488
  925.  10.811   .0027   .8197   .8737   .9998  1.0000   .0914  1.0000   .9367  1.0000   .0601    27.4354
  930.  10.753   .0027   .8316   .8380   .9997  1.0000   .0953  1.0000   .9354  1.0000   .0614    32.4218
  935.  10.695   .0027   .8413   .8010   .9993  1.0000   .0990  1.0000   .9342  1.0000   .0626    37.4082
  940.  10.638   .0027   .8237   .7739   .9985  1.0000   .1029  1.0000   .9329  1.0000   .0637    42.3948
  945.  10.582   .0025   .7807   .7525   .9971  1.0000   .1067  1.0000   .9316  1.0000   .0650    47.3821
  950.  10.526   .0024   .7546   .7405   .9718  1.0000   .1106  1.0000   .9299  1.0000   .0664    52.3699
  955.  10.471   .0024   .7306   .7465   .9420  1.0000   .1143  1.0000   .9283  1.0000   .0679    57.3580
  960.  10.417   .0023   .7215   .7435   .9133  1.0000   .1183  1.0000   .9267  1.0000   .0693    62.3462
  965.  10.363   .0023   .7181   .7405   .8725  1.0000   .1220  1.0000   .9251  1.0000   .0708    67.3348
  970.  10.309   .0021   .7145   .7156   .8242  1.0000   .1258  1.0000   .9235  1.0000   .0722    72.3241
  975.  10.256   .0021   .7245   .7156   .7735  1.0000   .1295  1.0000   .9220  1.0000   .0736    77.3136
  980.  10.204   .0020   .7576   .7465   .6754  1.0000   .1332  1.0000   .9204  1.0000   .0749    82.3034
  985.  10.152   .0020   .7980   .8032   .5793  1.0000   .1367  1.0000   .9189  1.0000   .0763    87.2932
  990.  10.101   .0018   .8296   .8660   .4345  1.0000   .1404  1.0000   .9174  1.0000   .0776    92.2844
  995.  10.050   .0014   .7756   .9245   .3502  1.0000   .1438  1.0000   .9160  1.0000   .0790    97.2771
 1000.  10.000   .0011   .7245   .9554   .2759  1.0000   .1474  1.0000   .9145  1.0000   .0803   102.2715
 1005.   9.950   .0009   .6967   .9728   .2309  1.0000   .1507  1.0000   .9065  1.0000   .0879   107.2668
 1010.   9.901   .0008   .6606   .9673   .1952  1.0000   .1542  1.0000   .8988  1.0000   .0954   112.2630
 1015.   9.852   .0006   .6151   .9470   .1655  1.0000   .1574  1.0000   .8911  1.0000   .1028   117.2601
 1020.   9.804   .0005   .6491   .9210   .1474  1.0000   .1607  1.0000   .8836  1.0000   .1101   122.2574
 1025.   9.756   .0005   .6414   .8839   .1426  1.0000   .1636  1.0000   .8762  1.0000   .1172   127.2548
 1030.   9.709   .0005   .6530   .8543   .1381  1.0000   .1666  1.0000   .8690  1.0000   .1242   132.2524
 1035.   9.662   .0004   .6836   .8032   .1025  1.0000   .1692  1.0000   .8618  1.0000   .1310   137.2506
 1040.   9.615   .0004   .7000   .7563   .1163  1.0000   .1719  1.0000   .8549  1.0000   .1378   142.2486
 1045.   9.569   .0006   .7072   .7156   .1980  1.0000   .1745  1.0000   .8480  1.0000   .1444   147.2453
 1050.   9.524   .0004   .6836   .6977   .1251  1.0000   .1771  1.0000   .8412  1.0000   .1509   152.2434
 1055.   9.479   .0003   .6639   .6813   .1117  1.0000   .1795  1.0000   .8346  1.0000   .1573   157.2417
 1060.   9.434   .0004   .6193   .6781   .1316  1.0000   .1818  1.0000   .8281  1.0000   .1636   162.2399
 1065.   9.390   .0004   .5988   .6682   .1685  1.0000   .1835  1.0000   .8217  1.0000   .1698   167.2377
```

Table 25. Tape 7 Output (Contd)

```
 1070.   9.346  .0007  .6230  .6426  .2645 1.0000  .1853 1.0000  .8154 1.0000  .1759    172.2342
 1075.   9.302  .0018  .6303  .6388  .6754 1.0000  .1863 1.0000  .8092 1.0000  .1819    177.2252
 1080.   9.259  .0023  .6804  .6649  .7735 1.0000  .1873 1.0000  .8031 1.0000  .1878    182.2137
 1085.   9.217  .0026  .6804  .7345  .7830 1.0000  .1881 1.0000  .7971 1.0000  .1936    187.2009
 1090.   9.174  .0027  .6491  .7913  .7892 1.0000  .1889 1.0000  .7990 1.0000  .1911    192.1875
 1095.   9.132  .0028  .6028  .8705  .7892 1.0000  .1893 1.0000  .8060 1.0000  .1833    197.1737
 1100.   9.091  .0026  .5311  .9227  .7923 1.0000  .1898 1.0000  .8129 1.0000  .1754    202.1606
 1105.   9.050  .0025  .4794  .9690  .7892 1.0000  .1885 1.0000  .8198 1.0000  .1676    207.1462
 1110.   9.009  .0024  .4655  .9818  .7830 1.0000  .1873 1.0000  .8268 1.0000  .1598    212.1361
 1115.   8.969  .0026  .4962  .9910  .7767 1.0000  .1868 1.0000  .8294 1.0000  .1570    217.1232
 1120.   8.929  .0027  .5311  .9803  .7735 1.0000  .1863 1.0000  .8309 1.0000  .1557    222.1095
 1125.   8.889  .0029  .5797  .9599  .7702 1.0000  .1849 1.0000  .8323 1.0000  .1544    227.0951
 1130.   8.850  .0030  .6151  .9335  .7735 1.0000  .1836 1.0000  .8337 1.0000  .1532    232.0802
 1135.   8.811  .0027  .5712  .8934  .7892 1.0000  .1811 1.0000  .8351 1.0000  .1519    237.0669
 1140.   8.772  .0025  .5440  .8454  .8191 1.0000  .1786 1.0000  .8365 1.0000  .1506    242.0546
 1145.   8.734  .0022  .5269  .7913  .8483 1.0000  .1735 1.0000  .8378 1.0000  .1494    244.5489
-9999.
   1    1    0    0    0    0    0    0      0.000      0.000
   3    1    1    3    0    0   47.019      4.100      4.100      0.000
  -99.000   -99.000       -99
  -99.000   -99.000   -99.000
 33TROPICAL MODEL
    0.000     0.000     0.000    10.000     0.000     0.000    0
 -99  -99  -99  -99
  -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000
  900.000  1145.000     5.000
   1
1.0000  1.0000
  900.  11.111  .0069  .8290 1.0000 1.0000 1.0000  .0111 1.0000  .7541 1.0000  .1250      2.4827
  905.  11.050  .0074  .8169  .9962 1.0000 1.0000  .0120 1.0000  .7531 1.0000  .1231      7.4458
  910.  10.989  .0080  .8126  .9944 1.0000 1.0000  .0131 1.0000  .7518 1.0000  .1212     12.4059
  915.  10.929  .0086  .8104  .9907 1.0000 1.0000  .0142 1.0000  .7498 1.0000  .1198     17.3630
  920.  10.870  .0093  .8190  .9858 1.0000 1.0000  .0155 1.0000  .7478 1.0000  .1185     22.3163
  925.  10.811  .0107  .8790  .9793 1.0000 1.0000  .0166 1.0000  .7458 1.0000  .1171     27.2629
  930.  10.753  .0115  .8870  .9713 1.0000 1.0000  .0179 1.0000  .7438 1.0000  .1157     32.2055
  935.  10.695  .0123  .8936  .9616 1.0000 1.0000  .0192 1.0000  .7419 1.0000  .1144     37.1442
  940.  10.638  .0128  .8818  .9547 1.0000 1.0000  .0206 1.0000  .7400 1.0000  .1130     42.0800
  945.  10.582  .0131  .8514  .9494  .9999 1.0000  .0220 1.0000  .7381 1.0000  .1118     47.0144
  950.  10.526  .0136  .8329  .9462  .9992 1.0000  .0235 1.0000  .7361 1.0000  .1111     51.9463
  955.  10.471  .0141  .8159  .9478  .9981 1.0000  .0249 1.0000  .7341 1.0000  .1104     56.8756
  960.  10.417  .0149  .8104  .9470  .9969 1.0000  .0265 1.0000  .7322 1.0000  .1097     61.8013
  965.  10.363  .0156  .8083  .9462  .9948 1.0000  .0280 1.0000  .7303 1.0000  .1091     66.7234
  970.  10.309  .0162  .8061  .9400  .9917 1.0000  .0297 1.0000  .7284 1.0000  .1084     71.6422
  975.  10.256  .0171  .8126  .9400  .9871 1.0000  .0313 1.0000  .7266 1.0000  .1077     76.5566
  980.  10.204  .0185  .8348  .9478  .9779 1.0000  .0330 1.0000  .7248 1.0000  .1071     81.4642
  985.  10.152  .0201  .8635  .9622  .9665 1.0000  .0346 1.0000  .7230 1.0000  .1064     86.3638
  990.  10.101  .0214  .8857  .9774  .9439 1.0000  .0363 1.0000  .7212 1.0000  .1058     91.2568
  995.  10.050  .0212  .8479  .9696  .9239 1.0000  .0380 1.0000  .7194 1.0000  .1051     96.1508
 1000.  10.000  .0207  .8125  .9948  .8951 1.0000  .0398 1.0000  .7177 1.0000  .1045    101.0475
 1005.   9.950  .0205  .7947  .9971  .8701 1.0000  .0415 1.0000  .7163 1.0000  .1053    105.9451
 1010.   9.901  .0200  .7672  .9964  .8456 1.0000  .0433 1.0000  .7149 1.0000  .1060    110.8451
 1015.   9.852  .0192  .7326  .9935  .8213 1.0000  .0450 1.0000  .7135 1.0000  .1068    115.7491
 1020.   9.804  .0200  .7596  .9887  .8010 1.0000  .0468 1.0000  .7122 1.0000  .1075    120.6489
 1025.   9.756  .0203  .7535  .9813  .7949 1.0000  .0485 1.0000  .7108 1.0000  .1082    125.5476
```

Table 25. Tape 7 Output (Contd)

1030.	9.709	.0209	.7622	.9747	.7887	1.0000	.0503	1.0000	.7095	1.0000	.1089	130.4431
1035.	9.662	.0204	.7848	.9622	.7339	1.0000	.0519	1.0000	.7082	1.0000	.1096	135.3412
1040.	9.615	.0218	.7972	.9527	.7563	1.0000	.0537	1.0000	.7069	1.0000	.1104	140.2323
1045.	9.569	.0249	.8018	.9400	.8479	1.0000	.0553	1.0000	.7056	1.0000	.1110	145.1076
1050.	9.524	.0227	.7848	.9353	.7697	1.0000	.0570	1.0000	.7043	1.0000	.1117	149.9942
1055.	9.479	.0221	.7698	.9307	.7489	1.0000	.0586	1.0000	.7031	1.0000	.1124	154.8835
1060.	9.434	.0225	.7356	.9297	.7794	1.0000	.0602	1.0000	.7019	1.0000	.1131	159.7710
1065.	9.390	.0238	.7205	.9271	.8238	1.0000	.0617	1.0000	.7006	1.0000	.1138	164.6521
1070.	9.346	.0267	.7397	.9210	.8897	1.0000	.0632	1.0000	.6994	1.0000	.1144	169.5184
1075.	9.302	.0301	.7447	.9201	.9779	1.0000	.0644	1.0000	.6982	1.0000	.1151	174.3677
1080.	9.259	.0328	.7823	.9262	.9871	1.0000	.0657	1.0000	.6970	1.0000	.1157	179.2038
1085.	9.217	.0340	.7823	.9447	.9881	1.0000	.0669	1.0000	.6959	1.0000	.1164	184.0338
1090.	9.174	.0341	.7596	.9593	.9888	1.0000	.0681	1.0000	.6952	1.0000	.1163	188.8634
1095.	9.132	.0336	.7235	.9786	.9888	1.0000	.0691	1.0000	.6948	1.0000	.1158	193.6954
1100.	9.091	.0317	.6601	.9692	.9892	1.0000	.0701	1.0000	.6944	1.0000	.1153	198.5369
1105.	9.050	.0300	.6218	.9966	.9888	1.0000	.0706	1.0000	.6940	1.0000	.1149	203.3867
1110.	9.009	.0297	.6097	.9983	.9881	1.0000	.0712	1.0000	.6936	1.0000	.1144	208.2381
1115.	8.969	.0313	.6365	.9992	.9875	1.0000	.0718	1.0000	.6938	1.0000	.1139	213.0817
1120.	8.929	.0330	.6661	.9981	.9871	1.0000	.0724	1.0000	.6941	1.0000	.1135	217.9169
1125.	8.889	.0348	.7024	.9954	.9868	1.0000	.0726	1.0000	.6944	1.0000	.1131	222.7429
1130.	8.850	.0363	.7326	.9913	.9871	1.0000	.0729	1.0000	.6948	1.0000	.1127	227.5614
1135.	8.811	.0342	.6956	.9839	.9866	1.0000	.0727	1.0000	.6951	1.0000	.1123	232.3904
1140.	8.772	.0329	.6760	.9728	.9913	1.0000	.0726	1.0000	.6954	1.0000	.1119	237.2259
1145.	8.734	.0315	.6629	.9593	.9934	1.0000	.0717	1.0000	.6957	1.0000	.1115	239.6472

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 -99.000   -99.000   -99.000
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 900.000  1145.000     5.000
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900.	11.111	.6232	.9980	1.0000	1.0000	1.0000	.9993	1.0000	.9965	1.0000	.0012	.9419
905.	11.050	.6229	.9977	.9998	1.0000	1.0000	.9993	1.0000	.9965	1.0000	.0012	2.8276
910.	10.989	.6227	.9975	.9997	1.0000	1.0000	.9993	1.0000	.9965	1.0000	.0012	4.7140
915.	10.929	.6225	.9975	.9995	1.0000	1.0000	.9993	1.0000	.9964	1.0000	.0013	6.6015
920.	10.870	.6225	.9977	.9992	1.0000	1.0000	.9994	1.0000	.9964	1.0000	.0013	8.4891
925.	10.811	.6227	.9987	.9986	1.0000	1.0000	.9994	1.0000	.9963	1.0000	.0014	10.3755
930.	10.753	.6225	.9990	.9980	1.0000	1.0000	.9994	1.0000	.9963	1.0000	.0014	12.2631
935.	10.695	.6219	.9990	.9970	1.0000	1.0000	.9994	1.0000	.9963	1.0000	.0014	14.1538
940.	10.638	.6213	.9989	.9963	1.0000	1.0000	.9994	1.0000	.9962	1.0000	.0015	16.0471
945.	10.582	.6206	.9983	.9958	1.0000	1.0000	.9994	1.0000	.9962	1.0000	.0015	17.9440
950.	10.526	.6202	.9981	.9954	1.0000	1.0000	.9994	1.0000	.9961	1.0000	.0016	19.8430
955.	10.471	.6200	.9977	.9956	1.0000	1.0000	.9994	1.0000	.9961	1.0000	.0016	21.7428
960.	10.417	.6198	.9975	.9955	1.0000	1.0000	.9994	1.0000	.9960	1.0000	.0016	23.6435
965.	10.363	.6197	.9974	.9954	1.0000	1.0000	.9994	1.0000	.9960	1.0000	.0017	25.5449
970.	10.309	.6192	.9974	.9947	1.0000	1.0000	.9994	1.0000	.9959	1.0000	.0017	27.4488
975.	10.256	.6193	.9975	.9947	1.0000	1.0000	.9994	1.0000	.9959	1.0000	.0017	29.3523
980.	10.204	.6202	.9981	.9956	1.0000	1.0000	.9994	1.0000	.9959	1.0000	.0018	31.2514
985.	10.152	.6213	.9965	.9970	1.0000	1.0000	.9994	1.0000	.9958	1.0000	.0018	33.1448

Table 25. Tape 7 Output (Contd)

990.	10.101	.6224	.9989	.9934	1.0000	1.0000	.9994	1.0000	.9958	1.0000	.0018	35.0326
995.	10.050	.6226	.9953	.9994	1.0000	1.0000	.9994	1.0000	.9957	1.0000	.0019	36.9197
1000.	10.000	.6223	.9975	.9997	1.0000	1.0000	.9994	1.0000	.9957	1.0000	.0019	38.8082
1005.	9.950	.6220	.9971	.9998	1.0000	1.0000	.9994	1.0000	.9956	1.0000	.0020	40.6981
1010.	9.901	.6215	.9964	.9998	1.0000	1.0000	.9995	1.0000	.9955	1.0000	.0021	42.5905
1015.	9.852	.6208	.9955	.9996	1.0000	1.0000	.9995	1.0000	.9954	1.0000	.0023	44.4864
1020.	9.804	.6210	.9962	.9993	1.0000	1.0000	.9995	1.0000	.9953	1.0000	.0024	46.3814
1025.	9.756	.6205	.9961	.9987	1.0000	1.0000	.9995	1.0000	.9951	1.0000	.0025	48.2789
1030.	9.709	.6202	.9963	.9983	1.0000	1.0000	.9995	1.0000	.9950	1.0000	.0026	50.1777
1035.	9.662	.6198	.9968	.9970	1.0000	1.0000	.9995	1.0000	.9949	1.0000	.0027	52.0789
1040.	9.615	.6193	.9971	.9962	1.0000	1.0000	.9995	1.0000	.9948	1.0000	.0028	53.9823
1045.	9.569	.6184	.9972	.9947	1.0000	1.0000	.9995	1.0000	.9947	1.0000	.0029	55.8902
1050.	9.524	.6178	.9968	.9942	1.0000	1.0000	.9995	1.0000	.9946	1.0000	.0031	57.8012
1055.	9.479	.6172	.9965	.9936	1.0000	1.0000	.9995	1.0000	.9945	1.0000	.0032	59.7152
1060.	9.434	.6165	.9956	.9935	1.0000	1.0000	.9995	1.0000	.9944	1.0000	.0033	61.6327
1065.	9.390	.6159	.9952	.9931	1.0000	1.0000	.9995	1.0000	.9944	1.0000	.0034	63.5530
1070.	9.346	.6156	.9957	.9922	1.0000	1.0000	.9995	1.0000	.9943	1.0000	.0035	65.4748
1075.	9.302	.6156	.9959	.9921	1.0000	1.0000	.9995	1.0000	.9942	1.0000	.0036	67.3967
1080.	9.259	.6167	.9968	.9930	1.0000	1.0000	.9995	1.0000	.9941	1.0000	.0037	69.3134
1085.	9.217	.6180	.9968	.9952	1.0000	1.0000	.9995	1.0000	.9940	1.0000	.0038	71.2235
1090.	9.174	.6186	.9962	.9967	1.0000	1.0000	.9994	1.0000	.9939	1.0000	.0038	73.1306
1095.	9.132	.6191	.9952	.9985	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0037	75.0352
1100.	9.091	.6186	.9936	.9994	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0036	76.9424
1105.	9.050	.6179	.9920	.9998	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0035	78.8532
1110.	9.009	.6176	.9915	.9999	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0035	80.7651
1115.	8.969	.6183	.9925	1.0000	1.0000	1.0000	.9994	1.0000	.9940	1.0000	.0034	82.6736
1120.	8.929	.6189	.9936	.9999	1.0000	1.0000	.9994	1.0000	.9941	1.0000	.0034	84.5791
1125.	8.889	.6195	.9947	.9997	1.0000	1.0000	.9994	1.0000	.9941	1.0000	.0034	86.4814
1130.	8.850	.6199	.9955	.9995	1.0000	1.0000	.9994	1.0000	.9941	1.0000	.0033	88.3818
1135.	8.811	.6190	.9945	.9990	1.0000	1.0000	.9994	1.0000	.9942	1.0000	.0033	90.2867
1140.	8.772	.6181	.9939	.9981	1.0000	1.0000	.9994	1.0000	.9942	1.0000	.0033	92.1962
1145.	8.734	.6169	.9934	.9967	1.0000	1.0000	.9993	1.0000	.9942	1.0000	.0032	93.1538

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900.	11.111	.2988	.9563	1.0000	1.0000	1.0000	.8078	1.0000	.3868	1.0000	.3812	1.7529
905.	11.050	.2962	.9524	.9989	1.0000	1.0000	.8111	1.0000	.3838	1.0000	.3799	5.2720
910.	10.989	.2943	.9511	.9983	1.0000	1.0000	.8145	1.0000	.3805	1.0000	.3784	8.8008
915.	10.929	.2910	.9505	.9971	1.0000	1.0000	.8176	1.0000	.3755	1.0000	.3763	12.3458
920.	10.870	.2888	.9531	.9957	1.0000	1.0000	.8208	1.0000	.3707	1.0000	.3742	15.9019
925.	10.811	.2911	.9722	.9930	1.0000	1.0000	.8237	1.0000	.3660	1.0000	.3720	19.4465
930.	10.753	.2882	.9745	.9899	1.0000	1.0000	.8267	1.0000	.3615	1.0000	.3700	23.0053
935.	10.695	.2849	.9765	.9855	1.0000	1.0000	.8294	1.0000	.3570	1.0000	.3679	26.5806
940.	10.638	.2806	.9730	.9829	1.0000	1.0000	.8322	1.0000	.3526	1.0000	.3658	30.1774
945.	10.582	.2751	.9636	.9810	1.0000	1.0000	.8348	1.0000	.3486	1.0000	.3640	33.8018

Table 25. Tape 7 Output (Contd)

950.	10.526	.2723	.9576	.9800	.9998	1.0000	.8374	1.0000	.3465	1.0000	.3631	37.4404
955.	10.471	.2700	.9524	.9805	.9906	1.0000	.8398	1.0000	.3444	1.0000	.3623	41.0904
960.	10.417	.2685	.9505	.9803	.9993	1.0000	.8423	1.0000	.3423	1.0000	.3614	44.7480
965.	10.363	.2672	.9498	.9800	.9987	1.0000	.8445	1.0000	.3403	1.0000	.3606	48.4122
970.	10.309	.2651	.9490	.9770	.9981	1.0000	.8468	1.0000	.3383	1.0000	.3598	52.0867
975.	10.256	.2645	.9511	.9770	.9970	1.0000	.8489	1.0000	.3363	1.0000	.3590	55.7640
980.	10.204	.2660	.9583	.9805	.9948	1.0000	.8511	1.0000	.3344	1.0000	.3582	59.4340
985.	10.152	.2683	.9676	.9858	.9918	1.0000	.8530	1.0000	.3325	1.0000	.3574	63.0925
990	10.101	.2690	.9742	.9923	.9845	1.0000	.8550	1.0000	.3306	1.0000	.3566	66.7473
995.	10.050	.2646	.9625	.9967	.9791	1.0000	.8569	1.0000	.3287	1.0000	.3558	70.4243
1000.	10.000	.2587	.9511	.9984	.9704	1.0000	.8587	1.0000	.3269	1.0000	.3551	74.1308
1005.	9.950	.2550	.9451	.9992	.9605	1.0000	.8604	1.0000	.3267	1.0000	.3555	77.8560
1010.	9.901	.2500	.9358	.9990	.9504	1.0000	.8622	1.0000	.3264	1.0000	.3560	81.6058
1015.	9.852	.2445	.9249	.9981	.9401	1.0000	.8638	1.0000	.3261	1.0000	.3564	85.3833
1020.	9.804	.2442	.9330	.9965	.9313	1.0000	.8654	1.0000	.3259	1.0000	.3568	89.1622
1025.	9.756	.2425	.9311	.9939	.9283	1.0000	.8668	1.0000	.3256	1.0000	.3573	92.9498
1030.	9.709	.2419	.9339	.9913	.9246	1.0000	.8683	1.0000	.3254	1.0000	.3577	96.7405
1035.	9.662	.2357	.9420	.9858	.8976	1.0000	.8693	1.0000	.3251	1.0000	.3581	100.5622
1040.	9.615	.2390	.9459	.9822	.9091	1.0000	.8709	1.0000	.3249	1.0000	.3585	104.3673
1045.	9.569	.2493	.9474	.9770	.9513	1.0000	.8722	1.0000	.3246	1.0000	.3589	108.1206
1050.	9.524	.2381	.9420	.9751	.9150	1.0000	.8734	1.0000	.3244	1.0000	.3593	111.9299
1055.	9.479	.2339	.9368	.9[illegible]31	.9052	1.0000	.8745	1.0000	.3242	1.0000	.3597	115.7603
1060.	9.434	.2348	.9258	.9728	.9193	1.0000	.8757	1.0000	.3239	1.0000	.3601	119.5861
1065.	9.390	.2391	.9214	.9716	.9412	1.0000	.8766	1.0000	.3237	1.0000	.3605	123.3907
1070.	9.346	.2467	.9267	.9684	.9683	1.0000	.8775	1.0000	.3235	1.0000	.3609	127.1574
1075.	9.302	.2538	.9284	.9678	.9943	1.0000	.8783	1.0000	.3232	1.0000	.3613	130.8886
1080.	9.259	.2588	.9412	.9712	.9970	1.0000	.8790	1.0000	.3230	1.0000	.3617	134.5947
1085.	9.217	.2610	.9412	.9793	.9973	1.0000	.8797	1.0000	.3228	1.0000	.3621	138.2897
1090.	9.174	.2606	.9330	.9846	.9974	1.0000	.8803	1.0000	.3231	1.0000	.3617	141.9865
1095.	9.132	.2605	.9223	.9927	.9974	1.0000	.8808	1.0000	.3239	1.0000	.3608	145.6839
1100.	9.091	.2570	.9037	.9956	.9975	1.0000	.8813	1.0000	.3246	1.0000	.3599	149.3989
1105.	9.050	.2539	.8885	.9990	.9974	1.0000	.8815	1.0000	.3253	1.0000	.3591	153.1295
1110.	9.009	.2534	.8846	.9995	.9973	1.0000	.8817	1.0000	.3260	1.0000	.3582	156.8623
1115.	8.969	.2567	.8938	.9998	.9971	1.0000	.8819	1.0000	.3266	1.0000	.3577	160.5790
1120.	8.929	.2599	.9037	.9994	.9970	1.0000	.8821	1.0000	.3272	1.0000	.3573	164.2794
1125.	8.889	.2637	.9161	.9986	.9970	1.0000	.8821	1.0000	.3278	1.0000	.3570	167.9606
1130.	8.850	.2664	.9249	.9973	.9970	1.0000	.8821	1.0000	.3284	1.0000	.3566	171.6285
1135.	8.811	.2631	.9139	.9949	.9974	1.0000	.8818	1.0000	.3290	1.0000	.3562	175.3132
1140.	8.772	.2605	.9071	.9905	.9980	1.0000	.8815	1.0000	.3295	1.0000	.3559	179.0107
1145.	8.734	.2579	.9026	.9846	.9984	1.0000	.8806	1.0000	.3301	1.0000	.3555	180.8659

```
-9999.
  6     3     3     0     0     0     0    0      0.000      0.000
  1     1     1     0     0     0    23.000      0.000      0.000      0.000
 -99.000   -99.000          -99
 -99.000   -99.000   -99.000
 331962 U S STANDARD
   0.000   100.000    60.000   195.704     1.501     0.000    0
-99  -99   -99  -99
 -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000
6000.000  7500.000    20.000
  0
1.0000  1.0000
6000.    1.667 5.07E-05 1.83E-02 6.00E-06 2.16E-02 5.07E-05 6.00E-05              .8452
6020.    1.661 5.10E-06 1.85E-02 6.02E-06 2.18E-02 1.53E-04 1.80E-04              .8469
```

Table 25. Tape 7 Output (Contd)

6040.	1.656	5.12E-06	1.87E-02	6.05E-06	2.21E-02	2.55E-04	3.01E-04	.8467
6060.	1.650	5.11E-06	1.88E-02	6.07E-06	2.23E-02	3.57E-04	4.23E-04	.8416
6080.	1.645	5.14E-06	1.90E-02	6.10E-06	2.25E-02	4.60E-04	5.45E-04	.8435
6100.	1.639	5.17E-06	1.92E-02	6.12E-06	2.28E-02	5.64E-04	6.67E-04	.8447
6120.	1.634	5.23E-06	1.96E-02	6.14E-06	2.30E-02	6.68E-04	7.90E-04	.8516
6140.	1.629	5.25E-06	1.98E-02	6.16E-06	2.32E-02	7.73E-04	9.13E-04	.8513
6160.	1.623	5.26E-06	1.99E-02	6.19E-06	2.35E-02	8.78E-04	1.04E-03	.8496
6180.	1.618	5.19E-06	1.98E-02	6.21E-06	2.37E-02	9.82E-04	1.16E-03	.8355
6200.	1.613	5.00E-06	1.92E-02	6.23E-06	2.39E-02	1.08E-03	1.29E-03	.8024
6220.	1.608	4.82E-06	1.86E-02	6.24E-06	2.42E-02	1.18E-03	1.41E-03	.7719
6240.	1.603	4.68E-06	1.82E-02	6.26E-06	2.44E-02	1.27E-03	1.54E-03	.7479
6260.	1.597	5.27E-06	2.06E-02	6.28E-06	2.46E-02	1.38E-03	1.66E-03	.8384
6280.	1.592	5.34E-06	2.11E-02	6.30E-06	2.48E-02	1.48E-03	1.79E-03	.8477
6300.	1.587	5.32E-06	2.11E-02	6.31E-06	2.51E-02	1.59E-03	1.91E-03	.8431
6320.	1.582	5.06E-06	2.02E-02	6.33E-06	2.53E-02	1.69E-03	2.04E-03	.7993
6340.	1.577	4.87E-06	1.96E-02	6.34E-06	2.55E-02	1.79E-03	2.17E-03	.7680
6360.	1.572	4.65E-06	1.88E-02	6.36E-06	2.57E-02	1.89E-03	2.29E-03	.7308
6380.	1.567	5.30E-06	2.16E-02	6.37E-06	2.59E-02	1.99E-03	2.42E-03	.8314
6400.	1.563	5.39E-06	2.21E-02	6.38E-06	2.62E-02	2.10E-03	2.55E-03	.8449
6420.	1.558	5.40E-06	2.23E-02	6.40E-06	2.64E-02	2.20E-03	2.68E-03	.8444
6440.	1.553	5.41E-06	2.24E-02	6.41E-06	2.66E-02	2.31E-03	2.81E-03	.8439
6460.	1.548	5.41E-06	2.26E-02	6.42E-06	2.68E-02	2.42E-03	2.93E-03	.8431
6480.	1.543	5.37E-06	2.26E-02	6.43E-06	2.70E-02	2.53E-03	3.06E-03	.8360
6500.	1.538	5.36E-06	2.27E-02	6.43E-06	2.72E-02	2.63E-03	3.19E-03	.8337
6520.	1.534	5.31E-06	2.26E-02	6.44E-06	2.74E-02	2.74E-03	3.32E-03	.8248
6540.	1.529	5.38E-06	2.30E-02	6.45E-06	2.76E-02	2.85E-03	3.45E-03	.8342
6560.	1.524	5.29E-06	2.28E-02	6.45E-06	2.78E-02	2.95E-03	3.58E-03	.8202
6580.	1.520	5.10E-06	2.21E-02	6.46E-06	2.80E-02	3.06E-03	3.71E-03	.7892
6600.	1.515	4.87E-06	2.12E-02	6.47E-06	2.82E-02	3.15E-03	3.84E-03	.7527
6620.	1.511	4.46E-06	1.95E-02	6.47E-06	2.84E-02	3.24E-03	3.97E-03	.6890
6640.	1.506	3.72E-06	1.64E-02	6.47E-06	2.85E-02	3.32E-03	4.10E-03	.5739
6660.	1.502	3.53E-06	1.56E-02	6.48E-06	2.87E-02	3.39E-03	4.22E-03	.5445
6680.	1.497	2.91E-06	1.30E-02	6.49E-06	2.89E-02	3.45E-03	4.35E-03	.4482
6700.	1.493	3.05E-06	1.37E-02	6.50E-06	2.92E-02	3.51E-03	4.48E-03	.4693
6720.	1.488	1.83E-06	8.47E-03	6.50E-06	2.94E-02	3.54E-03	4.61E-03	.2883
6740.	1.484	2.11E-06	9.58E-03	6.51E-06	2.96E-02	3.59E-03	4.74E-03	.3237
6760.	1.479	1.05E-06	4.79E-03	6.52E-06	2.98E-02	3.61E-03	4.88E-03	.1607
6780.	1.475	1.33E-06	6.10E-03	6.53E-06	3.00E-02	3.63E-03	5.01E-03	.2033
6800.	1.471	5.37E-07	2.48E-03	6.53E-06	3.02E-02	3.65E-03	5.14E-03	.0822
6820.	1.466	9.90E-07	4.60E-03	6.54E-06	3.04E-02	3.66E-03	5.27E-03	.1513
6840.	1.462	1.05E-06	4.93E-03	6.55E-06	3.06E-02	3.69E-03	5.40E-03	.1609
6860.	1.458	2.40E-06	1.13E-02	6.55E-06	3.08E-02	3.73E-03	5.53E-03	.3661
6880.	1.453	1.59E-06	7.50E-03	6.56E-06	3.10E-02	3.77E-03	5.66E-03	.2418
6900.	1.449	4.93E-07	2.35E-03	6.56E-06	3.12E-02	3.78E-03	5.79E-03	.0751
6920.	1.445	2.29E-07	1.10E-03	6.57E-06	3.14E-02	3.78E-03	5.92E-03	.0349
6940.	1.441	3.08E-07	1.48E-03	6.57E-06	3.17E-02	3.79E-03	6.05E-03	.0468
6960.	1.437	4.40E-07	2.13E-03	6.58E-06	3.19E-02	3.79E-03	6.19E-03	.0670
6980.	1.433	8.24E-08	4.01E-04	6.58E-06	3.21E-02	3.80E-03	6.32E-03	.0125
7000.	1.429	2.38E-07	1.17E-03	6.59E-06	3.23E-02	3.80E-03	6.45E-03	.0362
7020.	1.425	6.16E-08	3.03E-04	6.59E-06	3.25E-02	3.80E-03	6.56E-03	.0093
7040.	1.420	8.58E-08	4.25E-04	6.59E-06	3.27E-02	3.80E-03	6.71E-03	.0130
7060.	1.416	5.17E-08	2.58E-04	6.60E-06	3.29E-02	3.81E-03	6.84E-03	.0078
7080.	1.412	1.79E-08	8.95E-05	6.60E-06	3.31E-02	3.81E-03	6.98E-03	.0027
7100.	1.408	0.	0.	6.60E-06	3.33E-02	3.81E-03	7.11E-03	0.0000

Table 25. Tape 7 Output (Contd)

7120.	1.404	2.08E-09	1.05E-05	6.60E-06	3.35E-02	3.81E-03	7.24E-03	.0003
7140.	1.401	0.	0.	6.60E-06	3.37E-02	3.81E-03	7.37E-03	0.0000
7160.	1.397	0.	0.	6.60E-06	3.38E-02	3.81E-03	7.50E-03	0.0000
7180.	1.393	6.18E-10	3.19E-06	6.60E-06	3.40E-02	3.81E-03	7.64E-03	.0001
7200.	1.389	5.62E-10	2.91E-06	6.59E-06	3.42E-02	3.81E-03	7.77E-03	.0001
7220.	1.385	0.	0.	6.59E-06	3.43E-02	3.81E-03	7.90E-03	0.0000
7240.	1.381	0.	0.	6.58E-06	3.45E-02	3.81E-03	8.03E-03	0.0000
7260.	1.377	3.15E-10	1.66E-06	6.57E-06	3.46E-02	3.81E-03	8.16E-03	.0000
7280.	1.374	2.19E-10	1.16E-06	6.57E-06	3.48E-02	3.81E-03	8.29E-03	.0000
7300.	1.370	0.	0.	6.56E-06	3.50E-02	3.81E-03	6.43E-03	0.0000
7320.	1.366	0.	0.	6.55E-06	3.51E-02	3.81E-03	8.56E-03	0.0000
7340.	1.362	0.	0.	6.55E-06	3.53E-02	3.81E-03	8.69E-03	0.0000
7360.	1.359	0.	0.	6.54E-06	3.54E-02	3.61E-03	8.82E-03	0.0000
7380.	1.355	0.	0.	6.53E-06	3.56E-02	3.81E-03	8.95E-03	0.0000
7400.	1.351	1.11E-08	6.06E-05	6.53E-06	3.57E-02	3.81E-03	9.08E-03	.0017
7420.	1.348	1.04E-07	5.75E-04	6.53E-06	3.60E-02	3.81E-03	9.21E-03	.0160
7440.	1.344	8.74E-07	4.84E-03	6.55E-06	3.63E-02	3.83E-03	9.34E-03	.1335
7460.	1.340	1.75E-06	9.76E-03	6.57E-05	3.65E-02	3.86E-03	9.47E-03	.2671
7480.	1.337	2.13E-06	1.19E-02	6.58E-06	3.68E-02	3.90E-03	9.60E-03	.3229
7500.	1.333	2.44E-06	1.37E-02	6.60E-06	3.71E-02	3.93E-03	9.67E-03	.3703
-9999.								

Mie-generated database. The surface albedo is 0.05 and the surface temperature is 300°K. The spectral range of the calculation is from 4000 to 4500 cm^{-1} in steps of 10 cm^{-1}.

The output for this case shown in Table 19 will now be described. On page one, Table 19, the program echoes the input cards exactly as they are read in. CARD 1 selects the U.S. Standard Atmosphere (MODEL = 6), type of slant path (ITYPE = 2), single scattering option (IEMSCT = 2), surface temperature (TBOUND = 300.0), and surface albedo (SALB = 0.05). CARD 2 selects the RURAL aerosol profile with the default meteorological range of 23 km (IHAZE = 1). CARD 3 describes the slant path in terms of the observer altitude (H1 = 500 km), endpoint at the ground (H2 = 0) and zenith angle (ANGLE = 160.0°). On CARD 3A1 IPARM = 2 determines that the sun position will be described on CARD 3A2 in terms of the relative azimuth at H1 of 45° (PARM1) and the solar zenith angle at H1 of 60° (PARM2). IPH = 2 specifies that the Mie-generated phase function will be used, while IDAY = 1 specifies that the earth-to-sun distance used to calculate the incident solar intensity will be that for January 1. ISOURC = 0 specifies the sun as the source. On CARD 3A2, only PARM1 and PARM2, as described earlier, are used for this case. The remaining parameters are left blank. Card 4 selects the spectral range of 4000 to 4500 cm^{-1} in steps of 10 cm^{-1}. Following CARD 4 the program interprets the input cards in a more readable fashion.

The next two pages, labeled Atmospheric Profiles, list the profiles of pressure, temperature, and absorber densities at the indicated altitudes Z for the selected atmospheric model. The densities of the absorbers are as indicated or are in relative units (-). The densities of water vapor (H_2O), uniformly-mixed gases (CO_2+), ozone (O_3), and nitrogen continuum (N_2) are in scaled LOWTRAN units. 'CNTMSLF' and 'CNTMFRN' refer to the self- and foreign-broadened water vapor continuum density factors. The column labeled 'MOL SCAT' is the total air density relative to 1013.25 mb and 273.15K, which is used to calculate molecular scattering. 'N-1' is the refractivity or the index of refraction -1.0. The ultraviolet ozone [O_3(UV)] density is the actual density as is the nitric acid (HNO_3) density. AEROSOL 1 to 4 refer to the aerosol scaling factors for the four aerosol altitude regimes. 'AER1*RH' is AEROSOL 1 times the relative humidity (RH) and is used to calculate the path-averaged RH in the boundary layer. 'CIRRUS' is the cirrus cloud density profile in km^{-1} (see Section 7). Since the cirrus cloud option was not selected for this case, the cirrus density is zero everywhere.

After atmospheric profiles, messages are printed concerning the interpretation of the slant path parameters. In this case the observer altitude H1 is reset to the altitude of the highest atmospheric profile boundary (100 km). All possible

combinations of slant path parameters are reduced to the standard set of H1, H2, ANGLE, PHI, HMIN, and LEN, where PHI is the arrival angle at H2, HMIN is the altitude of the lowest point along the path, and LEN has a value of unity if the path goes through a tangent height and a value of zero otherwise.

A layer-by-layer description of the ray trace through the atmosphere appears next. The ray trace always begins at the lowest point along the path HMIN and proceeds upwards. The various quantities presented are: layer boundaries; zenith angle at the bottom of the layer THETA; curved path length through the layer DRANGE; cumulative path length RANGE from HMIN; earth-centered angle subtended by the layer DBETA and by the cumulative path BETA; arrival angle at the top of the layer PHI; path bending within the layer DBEND and cumulative BENDING; density-weighted path averaged pressure and temperature PBAR and TBAR for the layer; and average total air density RHOBAR.

The next table lists the cumulative absorber amounts for the species described in the atmospheric profile table from the observer to the different layer boundaries. 'CNTMSLF1' and 'CNTMSLF2' refer to the self-broadened water vapor amount and the temperature correction factor (Section 3). A summary of the geometry calculation appears next, followed by "Equivalent Sea Level Total Absorber Amounts" that are the total amounts for the whole path for each of the forementioned variables. "Mean RH" refers to the mean relative humidity in the boundary layer only.

Next is the output of the single solar scattering geometry routines: this includes a summary of the path from each scattering point to the sun. 'SUBTENDED ANGLE' is the earth-centered angle between the observer at H1 and the scattering point. The 'SOLAR ZENITH' angle is the astronomical or unrefracted zenith angle to the sun. However, if the refractive bending for the path to the sun is calculated to be greater than 0.1°, then the solar zenith angle is corrected by the bending and that path is calculated again (up to four times) until the correction for refraction is less than 0.1°.

The 'RELATIVE AZIMUTH' is negative because internally the azimuth angles are measured positive counterclockwise, while for the input cards, azimuth angles are specified positive clockwise. 'SCTTR ANGLE' is the scattering angle at that point. A message will be printed if any scattering point is in the shade.

Finally, the results of the calculation are printed. In this case, it is the radiance and the total transmittance for the path. The first two columns are the frequency and wavelength in wavenumbers (cm^{-1}) and micrometers (μm) respectively. The radiance is broken down by source: atmospheric radiance (including boundary emission), path scattered radiance, ground reflected

radiance, and the total radiance, each listed per cm^{-1} and μm. The next column "Integral" is the integrated radiance from the initial frequency. The last column lists the total transmittance from H1 to H2. A short summary is printed at the end of the table, including the actual boundary temperature used (if any) and the minimum and maximum values of the total radiance, which are useful in determining the limits for plotting.

The last item printed is the value of IRPT on CARD 5. In this case, IRPT = 1 indicates that another full set of input cards follows.

11.2 Case 2: Cirrus Cloud Model

Case 2 illustrates the cirrus cloud model. The cirrus model is selected by ICIR = 1 in CARD 2 and the cirrus parameters are read in on CARD 2A. Since the parameters CTHIK and CALT are input as zero, the default values appropriate to the Tropical model atmosphere are used. The message regarding the probability of clouds occurring is informative only, it has no effect on the results.

ITYPE = 2 on CARD 1 selects a slant path from H1 to H2. On CARD 3 the parameters specified are H1 = 7 km, H2 = 12 km, and RANGE = 500 km. This value of RANGE is the straight line distance between H1 and H2 and is used to calculate the value of ANGLE, which is the zenith angle at H1. The path is then traced using H1, H2, and ANGLE. Because of refraction the calculated slant path of 545.094 km is greater than the input RANGE.

Under Atmospheric Profiles, cirrus density is given at 11.0 km; at all other altitudes it is zero. When calculating path amounts, the program will linearly interpolate the cirrus density between 10 and 11 km, and between 11 and 12 km. The transmittance due to cirrus is independent of frequency and is printed only once, at the end of the table.

11.3 Case 3: Navy Maritime Aerosol Model

In Case 3, the Navy maritime aerosol model is selected by IHAZE = 3 on CARD 2. Since the current wind speed WSS and the 24-h average wind speed WHH are left as zero, these parameters default to the values appropriate for the tropical model atmosphere (MODEL = 1 on CARD 1). The air mass character parameter ICSTL defaults to 3 for all atmospheric models. The meteorological range VIS is determined by WSS, WHH, ICSTL, and the relative humidity. The relative humidity in the boundary layer is determined by the water vapor density profile for the selected model atmosphere. If a value for VIS is read in on CARD 2, that value would override the value calculated by the Navy maritime model. The scaling factors for the Navy maritime model are listed under Atmospheric Profiles as AEROSOL 1.

11.4 Case 4: Rain Model

Case 4 illustrates the use of the rain model, which is selected by a non-zero value of the rain rate parameter RAINRT on CARD 2. Selecting MODEL = 0 on CARD 1 alters the form of CARD 3, which now requires the altitude pressure, temperature, water vapor and ozone amounts, and path length for a constant pressure path. The transmittance due to rain is independent of frequency and is printed only once, at the end of the transmittance table.

11.5 Case 5: Vertical Structure Algorithm (VSA)

For Case 5, the vertical structure algorithm is selected by specifying IVSA on CARD 2. On CARD 2B, the cloud ceiling ZCVSA, cloud thickness ZTVSA, and the inversion height are left as zero. The combination of VIS = 5 km (determined by IHAZE = 5: urban aerosol model, 5-km VIS) and ZCVSA ≥ 0 selects a VSA Case 2 boundary layer aerosol profile. The cloud ceiling and cloud depth default to values for Case 2, that is, 1.8 and 0.2 km, respectively.

The VSA model generates a boundary-layer aerosol profile at nine altitudes between the ground and the cloud top shown in Table 23. This profile uses the aerosol type shown under IHAZE and the scaling factor shown under EXTINCTION. It also includes the relative humidity, which is set to 100 percent inside a cloud or fog.

The VSA boundary-layer aerosol profile is incorporated into the overall atmospheric profile by creating an internal MODEL = 7. The VSA profile is written to an array. Then the overall atmospheric profile is added to that array, starting at 0.01 km above the top of the VSA profile. Some of the profile boundaries are eliminated in order to keep the total number of profile boundaries under 34. This array is then read in by the subroutine NSMDL (non-standard model) as if it were a user-defined profile (MODEL = 7). Since the VSA model defines two aerosol types in the boundary layer and the program allows at most four aerosol regimes, the stratospheric aerosol regime is continued up to the top of the atmosphere and the upper atmospheric regime is eliminated.

11.6 Case 6: Directly Transmitted Solar Irradiance

Case 6 calculates the directly transmitted solar irradiance from 6000 to 7500 cm^{-1} for an observer at the ground and a solar zenith angle of 60°. This case is selected by IEMSCT = 3 on CARD 1. An ITYPE = 3 slant path is required: CARD 3 specifies the observer altitude H1 = 0.0, the apparent solar zenith angle at H1, ANGLE = 60°, and the day of the year IDAY = 74 (the Ides of March).

The spectral output consists of the transmitted solar irradiance and the incident solar irradiance, corrected for variations in the earth-to-sun distance according to the day of the year. Also given are the cumulative integrals of these two quantities and the total transmittance for the path from H1 to the sun.

11.7 Tape 7 Output

The spectral results from each successful case run are written to a file on UNIT = 7, along with a 10-line header identifying the parameters for the case. This file can then be used to further process the results. For example, the plot and filter programs described in Appendices A and B work from this file. A listing of this file for the six sample cases is given in Table 25.

The data on the file consists of a 10-line header followed by the spectral data. The header consists for the most part of images of the input control cards, with the default values supplied for parameters that have defaults, for example VIS on CARD 2. The first four lines of the header are CARD 1, CARD 2, CARD 2A, and CARD 2B. When the cirrus, VSA, and single scattering options are not selected, the images of their respective control cards are supplied with the parameters set equal to -99. The fifth line of the header is the image of CARD 2C1 and gives the number of atmospheric layers and title of the atmospheric profile. This data is given for all values of MODEL even though it is read in only for MODEL = 7. CARDS 2C2 and 2D are not included in the header. Line 6 contains the values of the path parameters on CARD 3 after they have been evaluated. CARDS 3B1 and 3B2 are not included. Lines 7 and 8 are the images of CARDS 3A1 and 3A2, with all the parameters set equal to -99 if the single scattering option is not selected. Line 9 is the image of CARD 4, the frequency card, and line 10 gives the value of IRPT from CARD 5.

Line 11 gives the values of the transmittance due to rain and cirrus clouds, in 2F9.4 format. Since these transmittances are independent of frequency, they are given only once per case.

The following lines contain the spectral output and differ depending on the type of calculation: transmittance, radiance, radiance with single scattering, or directly transmitted solar irradiance. For a transmittance calculation (IEMSCT = 0) each line of spectral data has the following format:

1.	frequency (cm^{-1})	F7.0
2.	wavelength (micrometer)	F8.3
3.	transmittance, total	
4.	transmittance, water vapor	
5.	transmittance, uniformly mixed gases	
6.	transmittance, ozone	

7.	transmittance, nitrogen continuum	
8.	transmittance, water vapor continuum	10F8.4
9.	transmittance, molecular scattering	
10.	transmittance, aerosol	
11.	transmittance, nitric acid	
12.	aerosol absorption	
13.	integrated absorption (cm^{-1})	F12.4

For either radiance or radiance with single scattering, the format is:

1.	frequency (cm^{-1})	F7.0
2.	wavelength (μm)	F8.3
3.	atmospheric radiance (W $cm^{-2}ster^{-1}(cm^{-1})^{-1}$)	
4.	atmospheric radiance (W $cm^{-2}ster^{-1}\ \mu m^{-1}$)	
5.	path scattered radiance (W $cm^{-2}ster^{-1}(cm^{-1})^{-1}$)	
6.	path scattered radiance (W $cm^{-2}ster^{-1}\ \mu m^{-1}$)	
7.	ground reflected radiance (W $cm^{-2}ster^{-1}(cm^{-1})^{-1}$)	9E9.2
8.	ground reflected radiance (W $cm^{-2}ster^{-1}\ \mu m^{-1}$)	
9.	total radiance (W $cm^{-2}ster^{-1}(cm^{-1})^{-1}$)	
10.	total radiance (W $cm^{-2}ster^{-1}\ \mu m^{-1}$)	
11.	integrated radiance (W $cm^{-2}ster^{-1}$)	
12.	total transmittance, H1 to H2	
13.	TEB1	
14.	TEB2SV	3F8.4

If the single scattering option is not selected (that is, IEMSCT = 1) then the path-scattered, ground-reflected AND TOTAL radiances are set to zero. TEB1 and TEB2SV are also defined only with the single scattering option: TEB1 is the total transmittance for the L-shaped path from H1 to H2 to the sun. TEB2SV is the total transmittance for the path from H1 to the last boundary before H2 to the sun.

For directly transmitted solar irradiance, the format is:

1.	frequency (cm^{-1})	F7.0
2.	wavelength (μm)	F8.3
3.	transmitted solar irradiance (W $cm^{-2}(cm^{-1})^{-1}$)	
4.	transmitted solar irradiance (W $cm^{-2}\ \mu m^{-1}$)	
5.	incident solar irradiance (W $cm^{-2}(cm^{-1})^{-1}$)	6E9.2
6.	incident solar irradiance (W $cm^{-2}\ \mu m^{-1}$)	
7.	integrated transmitted irradiance (W cm^{-2})	
8.	integrated incident irradiance (W cm^{-2})	
9.	total transmittance, H1 to sun	27X,F9.4

The end of the spectral data is marked by a frequency of -9999.

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Appendix A

LOWTRAN 6 Plot Program

The LOWTRAN 6 plot program, LOWPLT, is an independent program designed to plot the transmittance and/or radiance output of a LOWTRAN 6 run. The program will plot one file of data, several files of data, or the same file of data as many times as desired. Another feature of the plot program is the ability to choose any of the many variables produced by a transmittance run, radiance run, or a radiance with scattering run. Finally, the user is given the option of plotting these variables on individual plots or on the same plot. When plotting different variables on the same plot, it is important to define the proper scale for the Y-axis. The LOWTRAN 6 plot program uses Tape 7 as generated by a LOWTRAN 6 run.

This plot program utilizes plot routines unique to the CDC-6600 CALCOMP plotter. Therefore some minor changes may be necessary to accommodate a different computer plotting system. (See Section A3 for more details on CALCOMP system differences.)

A1. INSTRUCTIONS FOR USING THE LOWTRAN 6 PLOT PROGRAM

The plot program extracts the data to be plotted from Tape 7. To initiate the program five input cards are required.

A1.1 Input Data and Formats

The data necessary to specify a given plot are given by the following five cards:

CARD 1 PROGID, SCALE
(FORMAT (3A10, F10.4))

CARD 2 XSIZE, PFRBEG, PFREND, DELTAX, ITYP, IXAXIS, NUMFIL
(FORMAT (4F10.4, 3I5))

CARD 3 YSIZE, YRMIN, YRMAX, DELTAY, ICRV, IYAXIS, NMYDEC
(FORMAT (F10.4, 3E10.2, 3I5))

CARD 4 IRAD, ITRP
(FORMAT (5I5))

CARD 5 ISAMFL, ISAMPT
(FORMAT (2I5))

A1.2 Utilizing Input Cards

To produce multiple plots; input cards 2 through 5 must be repeated. To end plotting; the first value on the following input card 2 should be negative.

Definitions of the input card variables will be discussed in Section A2.

A2. BASIC INSTRUCTIONS

The various quantities to be specified on each of the five control cards are defined in this section.

A2.1 CARD 1 PROGID, SCALE

The variable PROGID is a 30 Hollerith character identification header that is printed as a banner at the start of the plot.

SCALE = Multiplicative factor to increase or decrease the plot size (usually = 1.0)

A2.2 CARD 2 XSIZE, PFRBEG, PFREND, DELTAX, ITYP, IXAXIS, NUMFIL

XSIZE = Length of X-axis in inches

PFRBEG = Beginning wavenumber on plot in cm^{-1} or wavelength in μm

PFREND = Ending wavenumber on plot in cm^{-1} or wavelength in μm

DELTAX = The interval between the numbered values on the X-axis

ITYP = 0 Radiance per μm vs μm
= 1 Radiance per cm^{-1} vs cm^{-1}
= 2 Transmittance vs μm
= 3 Transmittance vs cm^{-1}

IXAXIS	= 0	X-axis will be linear
	= 1	X-axis will be logarithmic
NUMFIL	= 0	uses next available file of data
	> 0	uses file of data specified by NUMFIL

A2.3 CARD 3 YSIZE, YRMIN, YRMAX, DELTAY, ICRV, IYAXIS, NMYDEC

YSIZE = Length of Y-axis in inches

YRMIN = Minimum transmittance or radiance value to be plotted

YRMAX = Maximum transmittance or radiance value to be plotted

In a log plot YRMIN and YRMAX are input as the values of the respective exponents. In a linear plot they are entered as the actual minimum and maximum value.

DELTAY = The interval between the numbered values on the Y-axis

ICRV	= 0	Normal plot of line
	> 0	Calls special plotting routine to plot dashed and dotted lines
	= 1	Solid line without symbols
	= 2	Dashed line without symbols
	= 3	Dotted line without symbols
	= 4	Alternating dashes and dots without symbols
	= 5	Alternating dashes and 2 dots without symbols
	= 6 to 10	Same as ICRV = 1 to 5 with symbols at every point
	> 10	Alternating dashes of different lengths
	< 0	Data points only using symbol number = |ICRV|, where symbol number refers to the computer-system plotting table
IYAXIS	= 0	Y-axis will be linear
	= 1	Y-axis will be logarithmic

NMYDEC = Number of digits to the right of the decimal point on the Y-axis

A2.4 CARD 4 IRAD, ITRP

If IEMSCT = 0,

IRAD = ITRP = 0 plot of total transmittance

ITRP	= 1	Plot of water vapor band transmittance
	= 2	Plot of uniformly mixed gases transmittance
	= 3	Plot of ozone transmittance
	= 4	Plot of nitrogen continuum transmittance
	= 5	Plot of water vapor continuum transmittance
	= 6	Plot of molecular scattering transmittance

= 7 Plot of aerosol transmittance

= 8 Plot of nitric acid transmittance

= 9 Plot of aerosol absorption

If IEMSCT = 1,

IRAD = 0 Plot of total transmittance

= 1 Plot of atmospheric radiance per cm^{-1} vs cm^{-1}

= 2 Plot of atmospheric radiance per μm vs μm

If IEMSCT = 2,

IRAD = 0 Plot of total transmittance

= 1 Plot of atmospheric radiance per cm^{-1} vs cm^{-1}

= 2 Plot of atmospheric radiance per μm vs μm

= 3 Plot of scattered radiance per cm^{-1} vs cm^{-1}

= 4 Plot of scattered radiance per μm vs μm

= 5 Plot of reflected radiance per cm^{-1} vs cm^{-1}

= 6 Plot of reflected radiance per μm vs μm

= 7 Plot of total radiance per cm^{-1} vs cm^{-1}

= 8 Plot of total radiance per μm vs μm

If IEMSCT = 3,

IRAD = 0 Plot of total transmittance

= 1 Plot of transmitted solar irradiance per cm^{-1} vs cm^{-1}

= 2 Plot of transmitted solar irradiance per μm vs μm

= 3 Plot of incident solar irradiance per cm^{-1} vs cm^{-1}

= 4 Plot of incident solar irradiance per μm vs μm

A2.5 CARD 5 ISAMFL, ISAMPT

ISAMFL and ISAMPT are set to handle the next set of data to be plotted. ISAMFL is used when the user wishes to plot a second, third or . . . , variable from the same file of LOWTRAN 6 Tape 7 data. The user should be sure that the range of the variable falls within the range as specified on the plot axis by CARD 2 and CARD 3.

ISAMFL = 0 Normal advance to next file of data

= 1 Rewind and stay on same file

ISAMPT = 0 Normal advance to new plot

= 1 Plot data on same physical plot

A3. THE AFGL COMPUTER SYSTEM CALCOMP PLOT ROUTINES

The program LOWPLT uses several AFGL computer-system CALCOMP plot calls that may differ from the system plotting routines available to the user. It is anticipated that with suitable adaptation of the CALCOMP plot calls including the calls to PLTID3, PLOT, ENDPLT, NUMBER, SYMBOL, and LINE plotting can be accomplished with minimal difficulty.

The general functions of the AFGL system CALCOMP plot routines are as follows:

1. CALL PLTID3 (PROGID, XMAX, YMAX, FACTOR, IDC)

This subroutine must be the first routine called as it initializes the plot.

PROGID = A 30-character hollerith array used as an identifier on the plot header

XMAX = Max dimension in X inches (X limit for entire plot) (real)

YMAX = Max dimension in Y inches (Y limit for entire plot) (real)

FACTOR = A multiplicative factor to change size of plotting (usually 1.0) in both the X and Y directions

IDC Directs plot output to different plot queues

= 1 - all plot files going to tapes (user specified)

2 - all scratch-test-runs (no file created)

3 - for pens - standard 11-in. black ballpoint pen plots

4 - for pen - 11-in. red ink pen

5 - for pen - 32-in. red ink pen

2. CALL ENDPLT - PHYSICAL END OF PROGRAM

Subroutine ENDPLT must be the last plotting subroutine called in all levels. ENDPLT will empty plotting buffers and write identifying information at the end of the page. A call to ENDPLT causes termination of the job.

3. CALL LINE (X, Y, N, K, J, L, XMIN, DX, YMIN, DY, SYMSZE)

Subroutine LINE produces a single line by connecting the points defined in the dimensioned variables X and Y.

X = Array of X values (real)

Y = Array of Y values (real)

N = Number of points to be plotted (integer)

K = Repeat cycle (usually K = 1) (integer)
When K = 2 the first, third, fifth, etc., points will be plotted.
When K = 3 the first, fourth, seventh, etc., points will be plotted, etc.
Example CALL LINE(X(1),X(2),N2 ......) This is usually used when X and Y arrays are one mixed array.

J = Control for using symbols (integer)
J = 0 will produce a line plot without symbols
J = 1 will produce a line plot with a symbol at every point
J = 2 will produce a line plot with a symbol at every second point etc., a negative J will suppress the lines between the points.

L = A number describing the symbol to be used. Only symbols whose integer equivalent is 0 to 13 are centered around the point (X, Y). For all others the point (X, Y) is at the lower left corner of the symbol.

XMIN = Starting value of X-axis, in units of X (real)

DX = The difference between the final value on X-axis and the starting value of X-axis divided by the length of X-axis in inches (real).

YMIN = Starting value of Y-axis, in units of Y (real).

DY = The difference between the final value on Y-axis and the starting value of Y-axis divided by the length of Y-axis in inches.

SYMSZE = A number defining the size of the symbol to be used at the point (X, Y) (real). (Default size is 0.08 in.)

4. CALL PLOT (X,Y,IC)

Subroutine PLOT is used to move the pen and to redefine a new origin.

X = X coordinate, in inches (real)

Y = Y coordinate, in inches (real)

IC = If IC = 2, pen down as pen moves to (X, Y) (integer)
If IC = 3, pen up as pen moves to X, Y.
If IC = -2 or -3 a new origin is defined at X, Y.

Note: The pen will move to location X, Y, on the page in all cases. X and Y are defined with respect to the previously defined origin. Page frame limits should be considered in all cases. If IC $\neq \pm 2$ or 3, an error message is printed.

5. CALL NUMBER (X, Y, HGHT, FPN, THETA, N)

Subroutine NUMBER will interpret and plot a real (floating point) number.

X = X coordinate of lower left-hand corner of first digit, in inches, relative to the current origin (real)

Y = Y coordinate of lower left-hand corner of first digit, in inches, relative to the current origin (real)

HGHT = Height of numbers to be plotted, in inches (real)

FPN = Number to be plotted (real)

THETA = Orientation of the number with respect to the X axis, counter-clockwise in degrees (real)

N = Number of digits after the decimal point (integer), N = -1 will suppress the decimal point

6. CALL SYMBOL (X, Y, HGHT, BCD, THETA, N)

Subroutine SYMBOL will draw a series of symbols as defined in the symbol table in the CALCOMP instruction manual.

X = Coordinate of the lower-left corner of the first character, in inches, relative to the current defined origin (real)

Y = Coordinate of the lower-left corner of the first character, in inches, relative to the current origin (real)

HGHT = The height of the characters, in inches (real). For pen plots the width of each character will be equal to the height.

BCD = This parameter and the last parameter in CALL to SYMBOL (called N) determine the type of annotation the routine produces. If BCD is the text to be used as annotation, usually BCD or A type format, the characters must be left-justified and contiguous in a single variable, in an array, or in a Hollerith literal. Parameter N must contain the number of characters to be plotted. If BCD is a single character of text, the text must be right-justified and parameter N = 0.

THETA = The angular orientation with respect to the X axis counterclockwise, degrees (real)

N = This parameter plus parameter BCD determines type of lettering/symbols produced by routine SYMBOL.
N > 0 - defines character count in array BCD, left-justified.
N = 0 - defines single characters to be plotted, right-justified.

N < 0 (negative) - determines the condition of the pen in the move from its present position to the place where the symbol is to be produced

If N = -1, the pen is up during the move, after which a symbol is produced. If N = -2 or less, the pen is down during the move, after which a symbol is produced.

Three of the CALCOMP plot calls from the AFGL plotting library used in LOWPLT, are not consistent with the standard CALCOMP versions. These calls and their possible modifications are as follows:

1. CALL PLTID3 - should be replaced with CALL PLOTS (0,0,LDEV) where LDEV is the plot device designation;

2. CALL ENDPLT - should be replaced with a plot completion call appropriate to the user's system; and

3. CALL LINE - a program modification must be made so that the starting value and the scaling factor immediately follow the data values in the X-array and the Y-array respectively.

A4. SAMPLE PLOTS

Five plots were run from the output of the sample cases shown in Section 11. The input file used to generate these plots is listed in Table A1.

The plot depicted in Figure A1 is a plot of three variables from CASE 1. The continuous line plot represents the atmospheric radiance, dashed line represents the path scattered radiance, and dotted line represents the total radiance.

Table A1. Sample Input File for Plot Program

```
LW ABREU LOW6TEST PLOTS             1.00
    8.0     4000.0     4500.0     50.0       1     0     0
    6.0      -11.       -8.0       1.0       1     1     1
    1    0
    1    1
    8.0     4000.0     4500.0     50.0       1     0     1
    6.0      -11.       -8.0       1.0       2     1     1
    3    0
    1    1
    8.0     4000.0     4500.0     50.0       1     0     1
    6.0      -11.       -8.0       1.0       3     1     1
    7    0
    0    0
    8.0      900.0     1150.0     50.0       3     0     2
    6.0        0.0        1.0      0.1       3     0     1
    0    1
    0    0
    8.0      900.0     1150.0     50.0       3     0     3
    6.0        0.0        1.0      0.1       1     0     1
    0    1
    1    1
    8.0      900.0     1150.0     50.0       3     0     3
    6.0        0.0        1.0      0.1       2     0     1
    0    7
    0    0
    8.0      900.0     1150.0     50.0       3     0     5
    6.0        0.0        1.0      0.1       5     0     1
    0    5
    0    0
    8.0     6000.0     7500.0    150.0       1     0     6
    6.0      -11.0       -5.0      1.0       2     1     1
    1    0
    1    1
    8.0     6000.0     7500.0    150.0       1     0     6
    6.0      -11.0       -5.0      1.0       4     1     1
    3    0
    0    0
   -1.0
```

The plot in Figure A2 is a plot of the water vapor transmittance for CASE 2. The plots in Figure A3 are taken from CASE 3. The continuous line represents the transmittance due to water vapor and the dashed line represents the aerosol transmittance. In Figure A4 the water vapor continuum transmittance from CASE 5 is plotted. The plot in Figure A5 taken from CASE 6 shows the incident and transmitted solar irradiance.

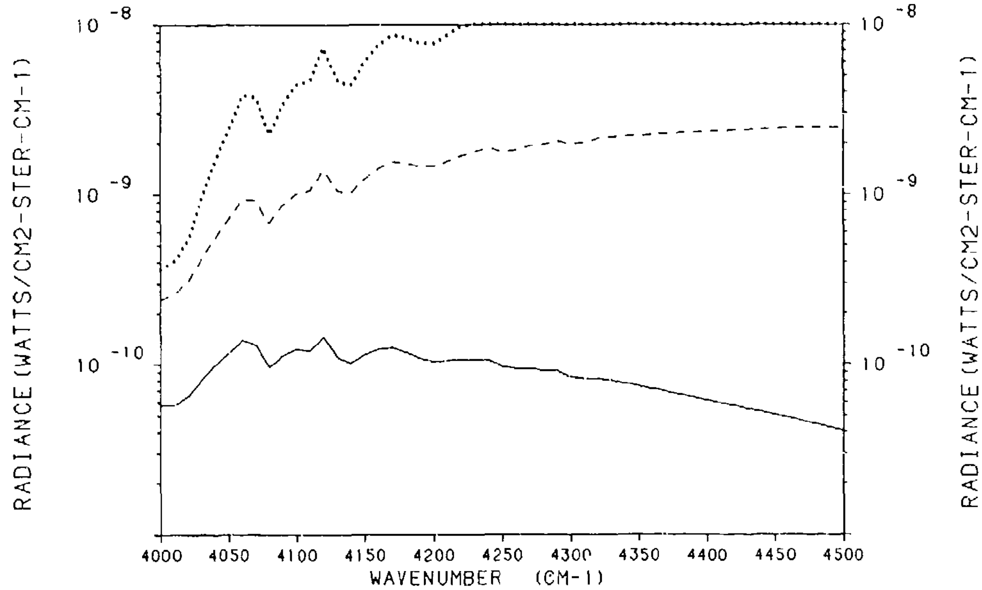

Figure A1. Three Variables are Plotted From Sample Case 1. The continuous line represents the atmospheric radiance, the dashed line represents the path scattered radiance, and the dotted line is the total radiance

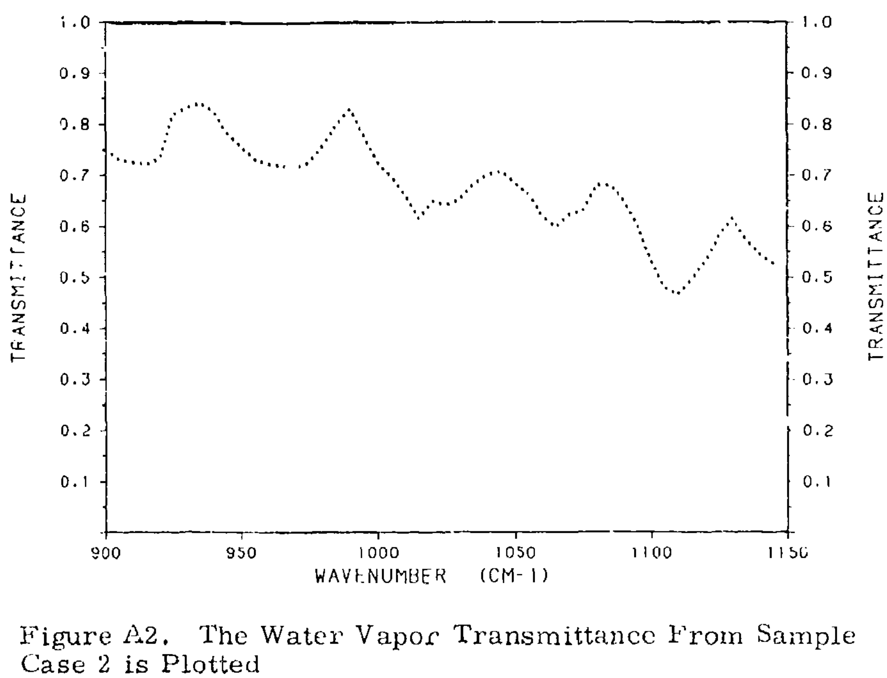

Figure A2. The Water Vapor Transmittance From Sample Case 2 is Plotted

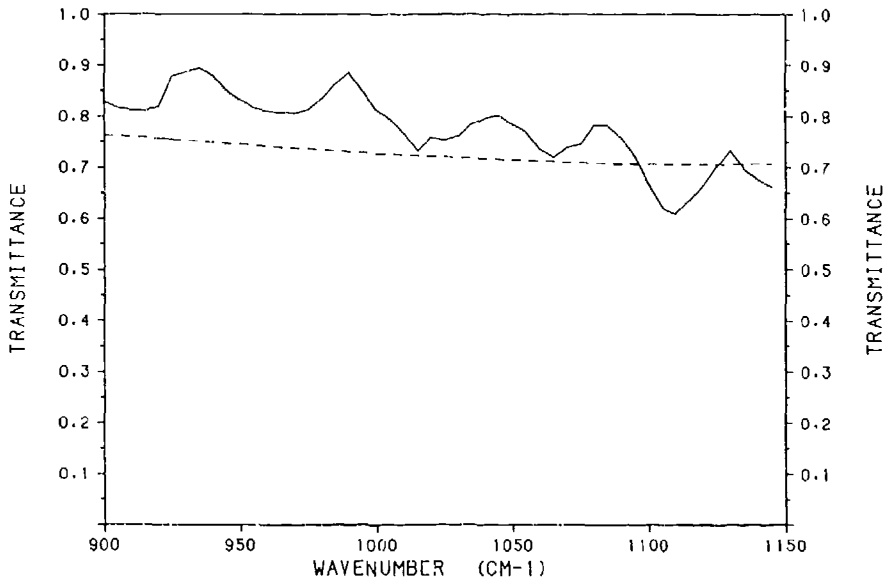

Figure A3. Two Variables From Sample Case 3 are Shown. The continuous line represents the transmittance due to water vapor and the dashed line represents the aerosol transmittance

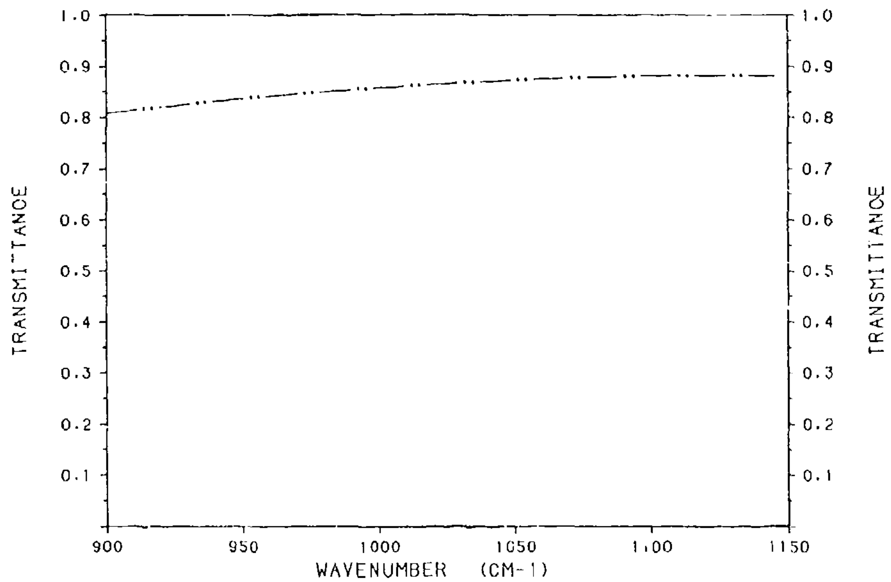

Figure A4. The Water Vapor Continuum Transmittance is Depicted by the Dashed/2 Dots Line

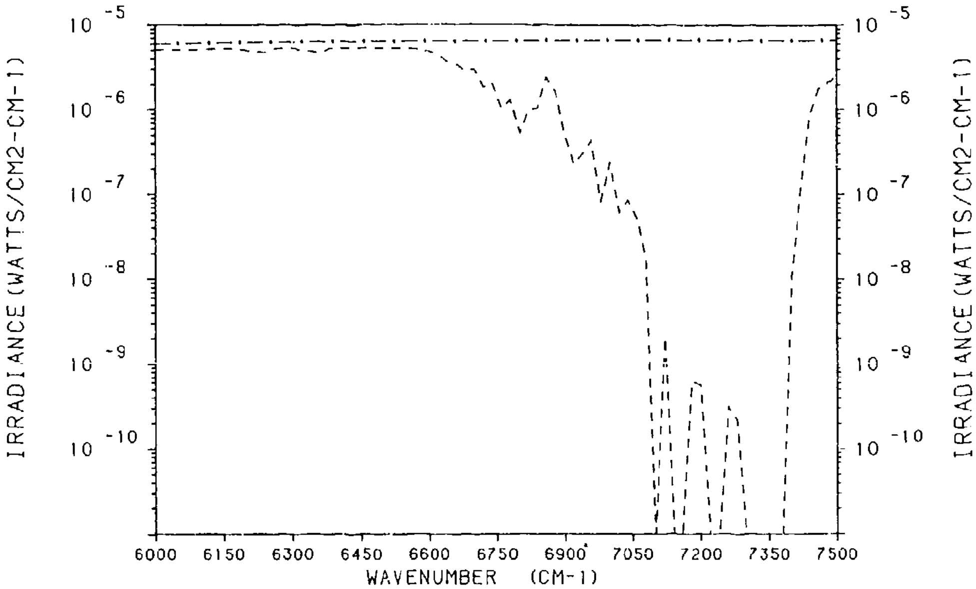

Figure A5. Two Variables From the Direct Solar Case 6 are Shown. The dashed line is the transmitted solar irradiance and the dashed/dotted line is the incident solar irradiance

Appendix B

LOWTRAN 6 Filter Function Program, LOWFIL

B1. INTRODUCTION

The LOWTRAN 6 Filter Function Program, LOWFIL, is primarily designed to calculate the effective atmospheric transmittance that would be measured by a filtered transmissometer. It can also be used to calculate the effective radiance seen by a radiometer measuring the radiance emitted or scattered by the atmosphere.

This program is written as an independent program package for use with the LOWTRAN 6 code. It assumes that the basic mass storage file, TAPE7, written by LOWTRAN, is available. It was written to be fairly flexible in its use, although it is recognized that users may wish to modify the code to tailor it more specifically for their own applications.

The effective average atmospheric transmittance measured by a transmissometer looking at a blackbody source is given by:

$$\bar{\tau} = \frac{\int \tau(\nu)\, F(\nu)\, B(\nu, T_{BB})\, d\nu}{\int F(\nu)\, B(\nu, T_{BB})\, d\nu}\,, \tag{B1}$$

where

$\tau(\nu)$ is the spectral transmittance of the atmosphere,

$F(\nu)$ is the total combined response function of the sensor, including the transmittance of any filter, the effect of the optical components and the detector response,

$B(\nu, T_{BB})$ is the spectral emissivity of the blackbody source,

T_{BB} is the temperature of the blackbody, and

ν is the frequency and the range of integration includes all the non-zero values of $F(\nu)$.

The atmospheric or scattered solar radiance measured by a radiometer is proportional to:

$$R = \int I(\nu) F(\nu) d\nu \quad , \tag{B2}$$

where $I(\nu)$ is the spectral radiance. In general when using Eq. (B2) to determine the radiance measured by a radiometer it would be necessary to include in $F(\nu)$, the radiometer angular field-of-view, calibration constants, and all other frequency independent quantities that can be neglected for Eq. (B1), since they cancel out. The effective normalized radiance is given by:

$$I_{Eff} = \frac{R}{F_{max}} = \frac{\int I(\nu) F(\nu) d\nu}{F_{max}} \quad , \tag{B3}$$

where F_{max} = the maximum value of $F(\nu)$. When used with radiance output, LOWFIL will calculate both R and I_{Eff}. The units of R will depend on the units of $F(\nu)$, the sensor response function; I_{Eff} will be in W/cm^2-ster.

The effective filter weighted average transmittances for the different atmospheric components used in LOWTRAN are also computed, (for example, the transmittance due to ozone, the water vapor continuum, aerosol etc.). It should be recognized, that while:

$$\tau(\nu) = \tau_{H20}(\nu)\, \tau_{C02} \cdots \tau_{HNO3}(\nu) \quad , \tag{B4}$$

in general:

$$\bar{\tau} \neq \bar{\tau}_{H20}\, \bar{\tau}_{C02} \cdots \bar{\tau}_{HNO3} \quad , \tag{B5}$$

where the average transmittance for each of the atmospheric components is found by evaluating an expression analogous to Eq. (B1).

In addition to the eight average component transmittances, the water continuum and band-type absorption are combined into a total water transmittance.

$$\tau_{Water}(\nu) = \tau_{H20\ Band}(\nu)\ \tau_{H20\ cont.}(\nu) \tag{B6}$$

Also the other gaseous transmittances are combined:

$$\tau_{Gas}(\nu) = \tau_{C02+}(\nu) \cdot \tau_{ozone}(\nu) \cdot \tau_{N2}(\nu) \cdot \tau_{mol.\ scat}(\nu) \cdot \tau_{HNO3}(\nu) \tag{B7}$$

These combined transmittance components have proved useful in developing simple analytic expressions for the effective transmittance measured by a system (for example, Shettle and Wise[1])

$$\bar{\tau} \approx \bar{\tau}_{Water} \cdot \bar{\tau}_{Gas} \cdot \bar{\tau}_{Aerosol} \quad , \tag{B8}$$

where analytic expressions are derived separately for τ_{Water}, τ_{Gas}, and $\tau_{Aerosol}$.

B2. COMPUTATIONAL DETAILS OF THE PROGRAM

The program starts by reading in a set of filter functions, or systems response functions. There can be up to 15 different filters each specified at up to 80 different wavelengths (these limits can be modified by adjusting the dimension statements) in each set.

The program is written so that the systems response functions or filter function $F(\nu)$, can be input either as a function of wavelength (μm) or as a function of wavenumber (cm^{-1}). If they are input as a function of wavelength, the wavelengths are converted to wavenumbers and the order of the points is reversed to be in ascending order in wavenumber.

Next, a specified number of LOWTRAN cases are read in from TAPE7 one at a time. For each LOWTRAN case, the different filters are cycled over one-by-one. The subset of the LOWTRAN wavenumbers, which bracket the values for which the filter is defined, are found for each filter in turn. Then the values of the filter function are interpolated to this subset of the LOWTRAN wavenumbers.

1. Shettle, E.P., and Wise, J.O. (1983) Simple Analytic Expressions for Atmospheric Transmittance (to be published).

Finally the integrals in Eqs. (B1) through (B3) are evaluated using the trapezoidal rule. After a set of filters is used with the specified number of LOWTRAN cases, the next set of filter functions is read in, and repeated until the input is terminated.

B3. USE OF THE FILTER FUNCTION PROGRAM

B3.1 General Remarks

The filter function program LOWFIL utilizes TAPE7, the standard mass storage output file as written by the LOWTRAN 6 computer code. The control cards for the filter are read from TAPE5, which in the listing that follows is equated to the INPUT file.

The program is written so that a set of up to 15 filter functions (system response functions) can be read in at once, and used with one or several consecutive LOWTRAN calculations. The filter functions can be input either as a function of wavelength (μm) or as a function of wavenumber (cm^{-1}). The wavelengths (wavenumbers) should be in ascending order, but can be at uneven intervals. An option is included to rewind the LOWTRAN TAPE7 output file, so more than 15 filter functions (system response functions) can be used or the same filters can be re-used with a different blackbody source temperature. It should be emphasized that the spectral range of the LOWTRAN calculations should include the full sensitive range of the systems response functions to be used.

B3.2 Control Cards

There are three (3) basic control cards:

CARD 1 NF, NEW, IFT, TEMP, IPRINT, NLOW
(FORMAT (3I5, F10.2, 2I5))

Repeat CARD 2 and CARD 3 "NF" times, where NF is specified on CARD 1.

CARD 2 IDFIL, KODE, IFWV, NW
(FORMAT (2A10, 3I5))

CARD 3 (WAVE (I), FF (I), I = 1, NW)

CARD 3 is a free format with as many cards as needed for all the values of WAVE and FF.

B3.2.1 CARD 1 NF, NEW, IFT, TEMP, IPRINT, NLOW

NF indicates number of different filters

NF > 0 Read in NF filters (NF $\leq$ 15)

= 0 Use preceding filter for next LOWTRAN output

< 0 Stop filter program

NEW is an option to reuse the previous LOWTRAN data set for the next set of filters.

NEW = 0, No, Read next NLOW sets of LOWTRAN data
    = 1, Yes, Rewind the LOWTRAN TAPE 7 output file

IFT is an option to enter blackbody temperature of source

IFT = 0 No blackbody
    = 1 Fold in blackbody emmissivity

TEMP = blackbody source temperature in degrees Kelvin

IPRINT controls the information printed

IPRINT = 10, Print LOWTRAN transmittances and results below
       = 5, Print filter function with blackbody function folded in
       = 0, Only print the filter weighted transmittances

NLOW indicates number of LOWTRAN data sets to use with this set of filters

B3.2.2 CARD 2 IDFIL, KODE, IFWV, NW

If NF is set to zero on CARD 1, a new input set of CARDS 2 and 3 are not read. If NF is > zero then "NF" input sets of CARD 2 and 3 are read.

IDFIL = 20 hollerith character identification for the given filter

KODE = Filter identification number (5 digits)

IFWV is an option to input the filter function either vs wavelength or vs wavenumber.

IFWV = 0 Wavelength
     = 1 Wavenumber

NW = Number of wavelengths or wavenumbers for the filter ($NW \leq 80$)

B3.2.3 CARD 3 (WAVE (I), FF (I), I = 1, NW)

The variable NW on input card 2 gives the number of wavelength or (wavenumber) filter function pairs necessary on CARD 3 or multiples of CARD 3. These should be in ascending order by wavelength (or wavenumber).

WAVE = Wavelength or wavenumber, depending on IFWV

FF = Corresponding filter function

B4. SAMPLE PROGRAM OUTPUT

This section presents a sample run of the Filter Function Program to illustrate its use. The contents of TAPE7 are assumed to be those produced by running LOWTRAN with the test cases described in Section 11. The input control cards are shown in Table B1.

Table B1. Sample Input Data for Filter Function Program

```
   1    1    1   5700.00    25    1
  2.29-2.41 MICRONS      1     0    13
2.29 0.    2.30 0.2  2.31 0.8   2.32 1.2   2.33 3.0   2.34 17.5
2.35 46.0 2.36 49.8 2.37 50.7 2.38 18.0 2.39 8.1   2.40 6.7
2.41 0.
   2    0    1    1133.     03    4
  9.12-10.57 MICRONS    2     0    30
  9.123  0.0  9.173  0.0  9.223   .3  9.273  1.0  9.323  1.8  9.373  3.3
  9.423  7.8  9.472 14.3  9.523 28.1  9.573 49.3  9.623 64.6  9.673 69.6
  9.723 69.1  9.773 66.8  9.823 65.2  9.873 67.1  9.923 72.9  9.973 77.7
 10.023 78.9 10.073 77.0 10.123 69.4 10.173 50.0 10.223 24.1 10.273  9.1
 10.323  3.7 10.373  2.6 10.423  1.4 10.473   .5 10.523  0.0 10.573  0.0
  9.48-11.08 MICRONS    3     0    33
  9.481  0.0  9.531  0.0  9.581   .0  9.631   .1  9.681  1.0  9.731  2.1
  9.781  2.3  9.831  5.2  9.881  9.4  9.931 17.1  9.981 32.1 10.031 51.6
 10.081 65.2 10.131 70.2 10.181 71.0 10.231 68.2 10.281 65.8 10.331 67.8
 10.381 72.0 10.431 75.5 10.481 77.8 10.531 77.3 10.581 71.2 10.631 55.0
 10.681 26.5 10.731 13.0 10.781  6.1 10.831  3.6 10.881  2.0 10.931   .7
 10.981   .0 11.031  0.0 11.081  0.0  0.000
   -1
```

It should be noted that one system response function is used with the first LOWTRAN test case, and the same two filter functions are used with each of the last four LOWTRAN cases. The first case uses a blackbody source temperature of 5700°K corresponding to the sun, since this is a solar scattering case. For the other cases the blackbody source temperature is 1133°K, the typical operating source temperature of the AFGL/OPA transmissometer system. The resulting output is shown in Table B2.

B5. STRUCTURE OF THE FILTER FUNCTION PROGRAM

A description of all the subroutines making up the Filter Function Program is given in Table B3, in the order in which they are called.

Table B2. Output for Filter Function Program

```
NUMBER OF FILTERS=     1   NEW=    1   IFT=    1  TEMPERATURE=   5700.00  IPRINT=   25  NLOW=    1


  FILTER NAME            FILT#  IFWV  NW
  2.29-2.41 MICRONS         1     0   13
WAVEL    FF   WAVEL    FF   WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF
 2.290  0.00   2.300   .20   2.310   .80   2.320  1.20   2.330  3.00   2.340 17.50   2.350 46.00   2.360 49.80   2.370 50.70
 2.380 18.00   2.390  8.10   2.400  6.70   2.410  0.00
 FILTER NAME            FILT#  IFWV  NW
  2.29-2.41 MICRONS         1     0   13
WAVEN    FF   WAVEN    FF   WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF
4149.4  0.00  4166.7  6.70  4184.1  8.10  4201.7 18.00  4219.4 50.70  4237.3 49.80  4255.3 46.00  4273.5 17.50  4291.8  3.00
4310.3  1.20  4329.0   .80  4347.8   .20  4366.8  0.00


 **************************************** LOWTRAN CONTROL DATA ****************************************
  6    2    2    0    0    0    0    0   300.000     .050
  1    1    1    0    0    0   23.000     0.000     0.000     0.000
 -99.000   -99.000       -99
 -99.000   -99.000  -99.000
 331982 U S STANDARD
 100.000     0.000   158.706   107.456     .351     0.000    0
  2    2    1    0
  45.000    60.000     0.000     0.000     0.000     0.000     0.000     0.000
4000.000  4500.000    10.000
  1

   LOWTRAN TAPE 7 OUTPUT    EMISSION CASE
RAIN=    1.0000  CIRRUS=   1.0000
 WAVEN   WAVEL     EMITTED RADIANCE    SCATTER RADIANCE    GND REFL RADIANCE   TOTAL RADIANCE       INTEGRAL TOT TRANS

  4000.   2.500  5.72E-11  9.15E-08  2.41E-10  3.85E-07  6.29E-11  1.01E-07  3.61E-10  5.77E-07  1.80E-09    .0707
  4010.   2.494  5.77E-11  9.29E-08  2.59E-10  4.16E-07  9.00E-11  1.45E-07  4.07E-10  6.54E-07  5.87E-09    .0800
  4020.   2.488  6.50E-11  1.05E-07  3.10E-10  5.02E-07  1.69E-10  2.74E-07  5.45E-10  9.80E-07  1.13E-08    .1075
  4030.   2.481  8.11E-11  1.32E-07  4.19E-10  6.80E-07  4.34E-10  7.04E-07  9.34E-10  1.52E-06  2.07E-08    .1659
  4040.   2.475  9.92E-11  1.62E-07  5.59E-10  9.11E-07  9.07E-10  1.48E-06  1.59E-09  2.55E-06  3.63E-08    .2405
  4050.   2.469  1.15E-10  1.91E-07  7.11E-10  1.17E-06  1.58E-09  2.59E-06  2.40E-09  3.94E-06  6.03E-08    .3212
  4060.   2.463  1.39E-10  2.30E-07  9.35E-10  1.54E-06  2.76E-09  4.54E-06  3.63E-09  6.31E-06  9.86E-08    .4345
  4070.   2.457  1.30E-10  2.16E-07  9.15E-10  1.52E-06  2.66E-09  4.40E-06  3.70E-09  6.13E-06  1.36E-07    .4199
  4080.   2.451  9.65E-11  1.61E-07  6.81E-10  1.13E-06  1.47E-09  2.45E-06  2.25E-09  3.74E-06  1.58E-07    .2979
  4090.   2.445  1.12E-10  1.89E-07  8.67E-10  1.45E-06  2.43E-09  4.06E-06  3.41E-09  5.70E-06  1.92E-07    .3891
  4100.   2.439  1.23E-10  2.06E-07  1.01E-09  1.71E-06  3.29E-09  5.52E-06  4.42E-09  7.44E-06  2.36E-07    .4609
  4110    2.433  1.21E-10  2.04E-07  1.05E-09  1.78E-06  3.51E-09  5.93E-06  4.68E-09  7.91E-06  2.83E-07    .4753
  4120.   2.427  1.45E-10  2.46E-07  1.39E-09  2.36E-06  5.75E-09  9.76E-06  7.28E-09  1.24E-05  3.56E-07    .6368
  4130.   2.421  1.10E-10  1.87E-07  1.05E-09  1.79E-06  3.49E-09  5.96E-06  4.65E-09  7.94E-06  4.03E-07    .4687
  4140.   2.415  1.02E-10  1.75E-07  1.02E-09  1.75E-06  3.29E-09  5.65E-06  4.41E-09  7.57E-06  4.47E-07    .4493
  4150.   2.410  1.14E-10  1.96E-07  1.23E-09  2.11E-06  4.63E-09  7.97E-06  5.97E-09  1.03E-05  5.05E-07    .5492
  4160.   2.404  1.23E-10  2.12E-07  1.42E-09  2.47E-06  5.99E-09  1.04E-05  7.54E-09  1.31E-05  5.82E-07    .6374
  4170.   2.398  1.25E-10  2.18E-07  1.55E-09  2.70E-06  6.98E-09  1.21E-05  8.66E-09  1.51E-05  6.68E-07    .6917
```

Table B2. Output for Filter Function Program (Contd)

4180.	2.392	1.18E-10	2.06E-07	1.52E-09	2.66E-06	6.98E-09	1.17E-05	8.32E-09	1.45E-05	7.52E-07	.6723
4190.	2.387	1.09E-10	1.92E-07	1.45E-09	2.57E-06	6.22E-09	1.09E-05	7.79E-09	1.37E-05	8.30E-07	.6428
4200.	2.381	1.04E-10	1.84E-07	1.46E-09	2.58E-06	6.15E-09	1.09E-05	7.72E-09	1.36E-05	9.07E-07	.6382
4210.	2.375	1.05E-10	1.87E-07	1.57E-09	2.78E-06	6.96E-09	1.23E-05	8.63E-09	1.53E-05	9.93E-07	.6870
4220.	2.370	1.07E-10	1.90E-07	1.69E-09	3.01E-06	7.92E-09	1.41E-05	9.71E-09	1.73E-05	1.09E-06	.7340
4230.	2.364	1.07E-10	1.91E-07	1.78E-09	3.19E-06	8.65E-09	1.55E-05	1.05E-08	1.89E-05	1.20E-06	.7682
4240.	2.358	1.06E-10	1.90E-07	1.87E-09	3.37E-06	9.45E-09	1.70E-05	1.14E-08	2.06E-05	1.31E-06	.8030
4250.	2.353	9.67E-11	1.75E-07	1.76E-09	3.19E-06	8.47E-09	1.52E-05	1.03E-08	1.86E-05	1.41E-06	.7546
4260.	2.347	9.48E-11	1.72E-07	1.82E-09	3.31E-06	8.87E-09	1.61E-05	1.08E-08	1.96E-05	1.52E-06	.7752
4270.	2.342	9.46E-11	1.73E 07	1.92E-09	3.51E-06	9.73E-09	1.77E-05	1.17E-08	2.14E-05	1.64E-06	.8130
4280.	2.336	9.29E-11	1.69E-07	1.97E-09	3.61E-06	1.01E-08	1.85E-05	1.22E-08	2.23E-05	1.76E-06	.8290
4290.	2.331	9.14E-11	1.66E-07	2.06E-09	3.79E-06	1.09E-08	1.99E-05	1.30E-08	2.39E-05	1.89E-06	.8614
4300.	2.326	8.47E-11	1.57E-07	1.99E-09	3.65E-06	1.00E-08	1.86E-05	1.21E-08	2.24E-05	2.01E-06	.8250
4310.	2.320	8.24E-11	1.53E-07	2.02E-09	3.75E-06	1.04E-08	1.93E-05	1.25E-08	2.32E-05	2.14E-06	.8393
4320.	2.315	8.25E-11	1.54E-07	2.14E-09	3.99E-06	1.14E-08	2.12E-05	1.36E-08	2.52E-05	2.27E-06	.8837
4330.	2.309	8.03E-11	1.50E-07	2.18E-09	4.09E-06	1.17E-08	2.19E-05	1.39E-08	2.61E-05	2.41E-06	.8981
4340.	2.304	7.74E-11	1.46E-07	2.20E-09	4.15E-06	1.18E-08	2.22E-05	1.41E-08	2.65E-05	2.55E-06	.9020
4350.	2.299	7.45E-11	1.41E-07	2.22E-09	4.20E-06	1.19E-08	2.25E-05	1.42E-08	2.68E-05	2.69E-06	.9030
4360.	2.294	7.17E-11	1.36E-07	2.25E-09	4.27E-06	1.20E-08	2.29E-05	1.43E-08	2.73E-05	2.84E-06	.9090
4370.	2.289	6.91E-11	1.32E-07	2.27E-09	4.34E-06	1.22E-08	2.33E-05	1.45E-08	2.78E-05	2.98E-06	.9153
4380.	2.283	6.66E-11	1.28E-07	2.30E-09	4.41E-06	1.23E-08	2.37E-05	1.47E-08	2.82E-05	3.13E-06	.9200
4390.	2.278	6.41E-11	1.24E-07	2.32E-09	4.47E-06	1.25E-08	2.40E-05	1.49E-08	2.85E-05	3.28E-06	.9235
4400.	2.273	6.17E-11	1.19E-07	2.34E-09	4.53E-06	1.26E-08	2.44E-05	1.50E-08	2.90E-05	3.43E-06	.9269
4410.	2.268	5.94E-11	1.16E-07	2.36E-09	4.59E-06	1.27E-08	2.47E-05	1.51E-08	2.94E-05	3.58E-06	.9307
4420.	2.262	5.71E-11	1.12E-07	2.38E-09	4.64E-06	1.28E-08	2.49E-05	1.52E-08	2.97E-05	3.73E-06	.9320
4430.	2.257	5.48E-11	1.07E-07	2.39E-09	4.68E-06	1.28E-08	2.51E-05	1.52E-08	2.99E-05	3.88E-06	.9320
4440.	2.252	5.27E-11	1.04E-07	2.41E-09	4.75E-06	1.29E-08	2.55E-05	1.54E-08	3.03E-05	4.04E-06	.9352
4450.	2.247	5.07E-11	1.00E-07	2.43E-09	4.82E-06	1.30E-08	2.58E-05	1.55E-08	3.07E-05	4.19E-06	.9381
4460.	2.243	4.87E-11	9.66E-08	2.45E-09	4.88E-06	1.31E-08	2.60E-05	1.56E-08	3.10E-05	4.35E-06	.9386
4470.	2.237	4.66E-11	9.32E-08	2.46E-09	4.91E-06	1.30E-08	2.61E-05	1.56E-08	3.11E-05	4.50E-06	.9366
4480.	2.232	4.47E-11	8.96E-08	2.47E-09	4.95E-06	1.30E-08	2.61E-05	1.55E-08	3.11E-05	4.66E-06	.9339
4490.	2.227	4.26E-11	8.59E-08	2.46E-09	4.97E-06	1.29E-08	2.60E-05	1.54E-08	3.10E-05	4.81E-06	.9279
4500.	2.222	4.06E-11	8.22E-08	2.45E-09	4.96E-06	1.26E-08	2.56E-05	1.51E-08	3.07E-05	4.65E-06	.9190

SUMMARY OF CALCULATIONS WITH FILTER# 1 FILTER NAME 2.29-2.41 MICRONS

IVF, IVL, NVL= 15 38 24 LOWTRAN WAVENUMBERS FROM 4140.00 TO 4370.00

FILTER RESPONSES AND TOTAL TRANSMITTANCES

WAVE	RESP	T	WAVE	RESP	T	WAVE	RESP	T	WAVE	RESP	T	WAVE	RESP	T
4140.	0.	.449	4150.	2.41E-01	.549	4160.	4.12E+00	.637	4170.	6.95E+00	.692	4180.	7.75E+00	.672
4190.	1.06E+01	.643	4200.	1.67E+01	.638	4210.	2.93E+01	.683	4220.	5.07E+01	.733	4230.	5.02E+01	.764
4240.	4.92E+01	.803	4250.	4.71E+01	.755	4260.	3.59E+01	.775	4270.	2.11E+01	.813	4280.	9.37E+00	.829
4290.	3.58E+00	.861	4300.	2.00E+00	.826	4310.	1.22E+00	.839	4320.	9.73E-01	.884	4330.	7.43E-01	.898
4340.	3.56E-01	.903	4350.	1.77E-01	.903	4360.	7.18E-02	.909	4370.	0.	.915			

FILTER RESPONSES WITH BLACKBODY EMISSIVITY

WAVE	RESP	T	WAVE	RESP	T	WAVE	RESP	T	WAVE	RESP	T	WAVE	RESP	T
4140.	0.	.449	4150.	1.11E-02	.549	4160.	1.90E-01	.637	4170.	3.22E-01	.692	4180.	3.60E-01	.672
4190.	4.94E-01	.643	4200.	7.80E-01	.638	4210.	1.37E+00	.683	4220.	2.39E+00	.733	4230.	2.37E+00	.768

Table B2. Output for Filter Function Program (Contd)

```
4240. 2.33E+00   .803     4250. 2.24E+00   .755     4260. 1.71E+00   .775     4270. 1.01E+00   .813     4280. 4.50E-01   .829
4290. 1.72E-01   .861     4300. 9.87E-02   .826     4310. 5.91E-02   .839     4320. 4.73E-02   .884     4330. 3.62E-02   .898
4340. 1.74E-02   .903     4350. 8.69E-03   .903     4360. 3.53E-03   .909     4370. 0.         .915

      SENSOR WEIGHTED INTEGRATED RADIANCES



VIS   BBTEMP EMIT RAD  SCAT RAD  REFL RAD  TOT RAD   TOT TRNS FILT#   NAME
23.0  5700. 3.589E-07 6.074E-06 2.912E-05 3.553E-05      .751    1  2.29-2.41 MICRONS

               FILTER NORMALIZED RADIANCES

             EMIT RAD  SCAT RAD  REFL RAD  TOT RAD
             7.082E-09 1.199E-07 5.748E-07 7.012E-07



NUMBER OF FILTERS=     2  NEW=    0  IFT=    1  TEMPERATURE=   1133.00  IPRINT=    3  NLOW=    4


  FILTER NAME          FILT#  IFWV  NW
  9.12-10.57 MICRONS     2     0    30
WAVEL    FF   WAVEL    FF   WAVEL    FF   WAVEL    FF   WAVEL    FF   WAVEL    FF   WAVEL    FF   WAVEL    FF   WAVEL    FF
 9.123  0.00   9.173  0.00   9.223   .30   9.273  1.00   9.323  1.80   9.373  3.30   9.423  7.80   9.473 14.30   9.523 28.10
 9.573 49.30   9.623 64.60   9.673 69.60   9.723 69.10   9.773 66.80   9.823 65.20   9.873 67.10   9.923 72.90   9.973 77.70
10.023 78.90  10.073 77.00  10.123 69.40  10.173 50.00  10.223 24.10  10.273  9.10  10.323  3.70  10.373  2.60  10.423  1.40
10.473   .50  10.523  0.00  10.573  0.00
  FILTER NAME         FILT#  IFWV  NW
  9.12-10.57 MICRONS     2     0    30
WAVEN    FF   WAVEN    FF   WAVEN    FF   WAVEN    FF   WAVEN    FF   WAVEN    FF   WAVEN    FF   WAVEN    FF   WAVEN    FF
 945.8  0.00   950.3  0.00   954.8   .50   959.4  1.40   964.0  2.60   968.7  3.70   973.4  9.10   978.2 24.10   983.0 50.00
 987.8 69.40   992.8 77.00   997.7 78.90  1002.7 77.70  1007.6 72.90  1012.9 67.10  1018.0 65.20  1023.2 66.80  1028.5 69.10
1033.8 69.60  1039.2 64.60  1044.6 49.30  1050.1 28.10  1055.6 14.30  1061.2  7.80  1066.9  3.30  1072.6  1.80  1078.4  1.00
1084.2   .30  1090.2  0.00  1096.1  0.00
```

Table B2. Output for Filter Function Program (Contd)

```
  FILTER NAME           FILT#  IFWV  NW
  9.48-11.08 MICRONS      3     0    33
WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF    WAVEL    FF
 9.481  0.00   9.531  0.00   9.581  0.00   9.631   .10   9.681  1.00   9.731  2.10   9.781  2.30   9.831  5.20   9.881  0.40
 9.931 17.10   9.981 32.10  10.031 51.60  10.081 65.20  10.131 70.20  10.181 71.00  10.231 68.20  10.281 65.80  10.331 67.80
10.381 72.00  10.431 75.50  10.481 77.80  10.531 77.30  10.581 71.20  10.631 55.00  10.681 28.50  10.731 13.00  10.781  6.10
10.831  3.60  10.881  2.00  10.931   .70  10.981  0.00  11.031  0.00  11.081  0.00
 FILTER NAME           FILT#  IFWV  NW
  9.48-11.08 MICRONS     3     0    33
WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF    WAVEN    FF
 902.4  0.00   906.5  0.00   910.7  0.00   914.8   .70   919.0  2.00   923.3  3.60   927.6  6.10   931.9 13.00   936.2 28.50
 940.6 55.00   945.1 71.20   949.6 77.30   954.1 77.80   958.7 75.50   963.3 72.00   968.0 67.80   972.7 65.80   977.4 68.20
 982.2 71.00   987.1 70.20   992.0 65.20   996.9 51.60  1001.9 32.10  1006.9 17.10  1012.0  9.40  1017.2  5.20  1022.4  2.30
1027.6  2.10  1033.0  1.00  1038.3   .10  1043.7  0.00  1049.2  0.00  1054.7  0.00


  ***************************************** LOWTRAN CONTROL DATA ****************************************
  1    2    0    0    0    0    0    0     0.000     0.000
  1    1    1    0    1    0   23.000     0.000     0.000     0.000
   1.000    11.000         0
 -99.000   -99.000   -99.000
 33TROPICAL MODEL
   7.000    12.000    91.670   545.094     4.890     0.000     1
-99  -99  -99  -99
 -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000
 900.000  1145.000     5.000
  1


             SUMMARY OF CALCULATIONS WITH  FILTER#  2  FILTER NAME   9.12-10.57 MICRONS


                               SENSOR WEIGHTED AVERAGE TRANSMITTANCES


                    TOT TRANS   H2O BAND    CO2     OZONE     N2 CONT    H2O CONT  MOL SCT   AER TRANS  HNO3
CONSTITUENT TRANS.=  1  .001,   2  .702,  3  .862,  4  .255,  5 1.000,  6  .156,  7 1.000,  8  .888,  9 1.000,
 T2TOS=  .001    TWGA=   .001    TRAIN=  1.000    TCIRRUS=   .044

 VIS   BBTEMP TTOT TH2O TGAS TAER FILT#    NAME
 23.0   1133.  .001 .109 .218 .888     2  9.12-10.57 MICRONS
```

Table B2. Output for Filter Function Program (Contd)

```
                 SUMMARY OF CALCULATIONS WITH  FILTER#  3  FILTER NAME   9.48-11.08 MICRONS


                                 SENSOR WEIGHTED AVERAGE TRANSMITTANCES
                       TOT TRANS   H2O BAND    CO2      OZONE      N2 CONT   H2O CONT  MOL SCT   AER TRANS  HNO3
CONSTITUENT TRANS.=  1  .002,  2  .755,  3  .790,  4  .736,  5 1 000,  6  .125,  7 1.000,  8  .923,  9 1.000,
 T2TO9=  .002    TWGA=   .002    TRAIN=  1.000    TCIRRUS=   .044

 VIS   BBTEMP TTOT TH2O TGAS TAER FILT#    NAME
 23.0  1133. .002 .094 .565 .923     3  9.48-11.08 MICRONS


****************************************** LOWTRAN CONTROL DATA ****************************************
 1     1    0    0    0    0    0    0     0.000      0.000
 3     1    1    3    0    0    47.019     4.100      4.100      0.000
 -99.000    -99.000       -99
 -99.000    -99.000    -99.000
 33TROPICAL MODEL
   0.000     0.000     0.000     10.000     0.000      0.000     0
-99  -99   -99   -99
 -99.000    -99.000    -99.000   -99.000    -99.000    -99.000    -99.000    -99.000
 900.000   1145.000     5.000
  1

                 SUMMARY OF CALCULATIONS WITH  FILTER#  2  FILTER NAME   9.12-10.57 MICRONS


                                 SENSOR WEIGHTED AVERAGE TRANSMITTANCES
                       TOT TRANS   H2O BAND    CO2      OZONE      N2 CONT   H2O CONT  MOL SCT   AER TRANS  HNO3
CONSTITUENT TRANS.=  1  .021,  2  .796,  3  .574,  4  .848,  5 1.000,  6  .045,  7 1.000,  8  .714,  9 1.000,
 T2TO9=  .021    TWGA=   .021    TRAIN=  1.000    TCIRRUS=  1.000

 VIS   BBTEMP TTOT TH2O TGAS TAER FILT#    NAME
 47.0  1133. .021 .036 .827 .714     2  9.12-10.57 MICRONS

                 SUMMARY OF CALCULATIONS WITH  FILTER#  3  FILTER NAME   9.48-11.08 MICRONS


                                 SENSOR WEIGHTED AVERAGE TRANSMITTANCES
                       TOT TRANS   H2O BAND    CO2      OZONE      N2 CONT   H2O CONT  MOL SCT   AER TRANS  HNO3
```

Table B2. Output for Filter Function Program (Contd)

```
CONSTITUENT TRANS.=  1  .017,  2  .834,  3  .958,  4  .972,  5 1.000,  6  .030,  7 1.000,  8  .723,  9 1.000,
 T2TO9=  .017     TWGA=    .017    TRAIN=  1.000    TCIRRUS=  1.000

 VIS   BBTEMP TTOT TH2O TGAS TAER FILT#    NAME
 47.0  1133. .017 .025 .930 .729     3  9.48-11.08 MICRONS


 ****************************************** LOWTRAN CONTROL DATA *****************************************
  0     1     0     0     0     0     0    0       0.000     0.000
  1     1     1     0     0     0    23.000      0.000     0.000     10.000
 -99.000   -99.000        -99
 -99.000   -99.000   -99.000
  1MODEL  =0HORIZONTAL
   0.000  1013.000     10.000  0.0 10.0 0.        0.              .300
-99  -99   -99  -99
 -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000
 900.000  1145.000     5.000
  1

                SUMMARY OF CALCULATIONS WITH  FILTER#  2  FILTER NAME   9.12-10.57 MICRONS


                                     SENSOR WEIGHTED AVERAGE TRANSMITTANCES
                  TOT TRANS   H2O BAND    CO2      OZONE      N2 CONT    H2O CONT   MOL SCT    AER TRANS  HNO3
CONSTITUENT TRANS.=  1  .621,  2  .997,  3  .998,  4 1.000,  5 1.000,  6  .999,  7 1.000,  8  .995,  9 1.000,
 T2TO9=  .621    TWGA=   .621     TRAIN=   .627    TCIRRUS=  1.000

 VIS    T      DP     P       RANGE BBTEMP TTOT TH2O TGAS TAER FILT#   NAME
23.0  10.0    0.0 1013.       .300 1133. .621 .997  .998 .995    2  9.12-10.57 MICRONS

                SUMMARY OF CALCULATIONS WITH  FILTER#  3  FILTER NAME   9.48-11.08 MICRONS
```

Table B2. Output for Filter Function Program (Contd)

```
                              SENSOR WEIGHTED AVERAGE TRANSMITTANCES
                 TOT TRANS   H2O BAND    CO2      OZONE      N2 CONT   H2O CONT  MOL SCT   AER TRANS  HNO3
CONSTITUENT TRANS.=  1  .621,  2  .998,  3  .996,  4 1.000,  5 1.000,  6  .999,  7 1.000,  8  .996,  9 1.000,
 T2TO9=  .621    TWGA=   .621    TRAIN=   .627    TCIRRUS=  1.000

 VIS    T     DP     P       RANGE BBTEMP TTOT TH2O TGAS TAER FILT#   NAME
23.0  10.0   0.0 1013.        .300 1133. .621 .997  .996 .996    3  9.48-11.08 MICRONS


 **************************************** LOWTRAN CONTROL DATA *******************************************
  7    2    0    6    6    6    0    0      0.000     0.000
  6    1    1    0    0    1    50.000     0.000     0.000     0.000
 -99.000   -99.000      -99
  0.000     0.000     0.000
 321902 U S STANDARD


   0.000     1.600    45.000    2.545      .016     0.000     0
 -99  -99   -99  -99
  -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000   -99.000
 900.000  1145.000     5.000
   1

              SUMMARY OF CALCULATIONS WITH  FILTER#  2  FILTER NAME   9.12-10.57 MICRONS


                              SENSOR WEIGHTED AVERAGE TRANSMITTANCES
                 TOT TRANS   H2O BAND    CO2      OZONE      N2 CONT   H2O CONT  MOL SCT   AER TRANS  HNO3
CONSTITUENT TRANS.=  1  .251,  2  .946,  3  .991,  4  .948,  5 1.000,  6  .863,  7 1.000,  8  .327,  9 1.000,
 T2TO9=  .251    TWGA=   .251    TRAIN=  1.000    TCIRRUS=  1.000

 VIS   BBTEMP TTOT TH2O TGAS TAER FILT#   NAME
 50.0  1133. .251 .816 .940 .327    2  9.12-10.57 MICRONS

              SUMMARY OF CALCULATIONS WITH  FILTER#  3  FILTER NAME   9.48-11.08 MICRONS
```

Table B2. Output for Filter Function Program (Contd)

```
                                SENSOR WEIGHTED AVERAGE TRANSMITTANCES
                      TOT  TRANS    H20 BAND    CO2      OZONE      N2 CONT    H20 CONT   MOL SCT    AER TRANS   HNO3
CONSTITUENT TRANS.=   1   .268,   2  .958,   3  .984,   4  .992,   5 1.000,   6  .846,   7 1.000,   8  .339,   9 1.000,
 T2TO9=  .268     TWGA=   .268     TRAIN=  1.000    TCIRRUS=  1.000

 VIS    BBTEMP TTOT TH2O TGAS TAER FILT#    NAME
  50.0  1133.  .268 .810 .976 .339    3  9.48-11.08 MICRONS



NUMBER OF FILTERS=    -1  NEW=    0  IFT=    0  TEMPERATURE=     0.00  IPRINT=    0  NLOW=    0
```

Table B3. Description of LOWTRAN Filter Program Subroutines

LOWFIL	- Main driver program. Reads control cards and TAPE7 output from LOWTRAN
WAVEN	- Changes a system response function vs wavelength (μm) to a response function vs wavenumber (cm^{-1})
BRACK	- Finds the LOWTRAN wavenumbers, which bracket the system response function
INTLOG	- Interpolates a pair of vectors, $F(I) = f(x_i)$, and $X(I) = X_i$, $i = 1, 2, \ldots N$, to a new set of coordinates; FNEW $(J) = f(x_j)$ and XNEW $(J) = x_j$, $j = 1, 2, \ldots M$
BIGFIL	- Routine to find the maximum value of the system response function
INTRAD	- Integrates the emitted or scattered radiance from LOWTRAN times the systems response function
BLKBDY	- Weights the system response function by a blackbody radiance
INTGRT	- Finds the average value of the transmittance from LOWTRAN weighted by the systems response function
COMBT	- Finds the weighted average transmittance due to water vapor (both band-type and continuum combined) and all the other gases combined together

Appendix C

Single Scattering Geometry

The single scattering algorithm requires the scattering angle and the equivalent absorber amounts for the primary solar paths from each scattering point along the line-of-sight. This calculation involves tracking two optical paths for each scattering point. One path leg extends from the observer to the scattering point, and the other from the scattering point toward the sun (or moon), ending at the top of the atmosphere (nominally 100 km). Each path will, in general, be bent by refraction but each remains in a fixed vertical plane containing the path endpoints and the center of the earth. The intersection of the two planes at each scattering point defines the scattering angle.

The optical path within each plane can be described in a spherical coordinate system in terms of the initial altitude and the zenith angle at that altitude. The new air mass module (Section 2) is used repeatedly: first to trace the line-of-sight path from the observer to the endpoint, tracking the altitude, zenith angle, and absorber amounts at each scattering point. Next, it is called at each scattering point to trace the path from the scattering point to the sun.

Aside from the in-plane tracking of each path leg, it is necessary to determine the angle of intersection of the two vertical planes, which is also the azimuthal angle separating the projections of the two path legs onto the earth's surface. The projection of a path segment onto the earth forms part of a great circle on the earth, since a vertical plane always includes the earth center. The projected path segments for a typical geometrical configuration are shown in

Figure C1 from a perspective above the earth's surface looking down. The relative azimuth angle $\psi_{r,p}$ between the projected path legs at the projected scattering point is found by first computing the absolute azimuth angle for the observer-to-subsolar-point projection OS. The absolute line-of-sight azimuth $\psi_{a,op}$ is required as an input to the code. Within the program, absolute azimuth angles are measured from the local east direction, with positive angles indicating north-of-east in this discussion. In the LOWTRAN input directives, however, absolute azimuths are specified in the clockwise sense from north, that is, positive east-of-north. A conversion from one convention to the other occurs within the code. The relative azimuth angle at the observer $\psi_{r,o}$ is calculated next. A transformation of the coordinate system of the optical path is then made to facilitate the calculation of the relative azimuth angle $\psi_{r,p}$ at each scattering point. This angle allows precise calculation of the scattering angle at each point.

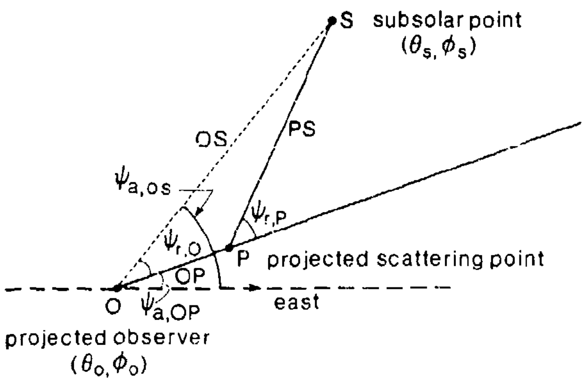

Figure C1. Looking Down on the Scattering Path. All points are projected on the earth and all line segments are parts of great circles. The relative azimuth can be seen to vary as one moves the scattering point along OP

The subsolar point and the projected observer position together define the great circle $\theta(\phi)$, which satisfies the condition

$$\tan \theta = A \cos \phi + B \sin \phi \quad , \tag{C1}$$

where θ and ϕ are the standard latitude and longitude angles shown in Figure C2 and A and B are constants to be found. The case where the subsolar point and observer lie on the same longitude, $\tan \phi_s = \tan \phi_o$, is treated separately since ϕ

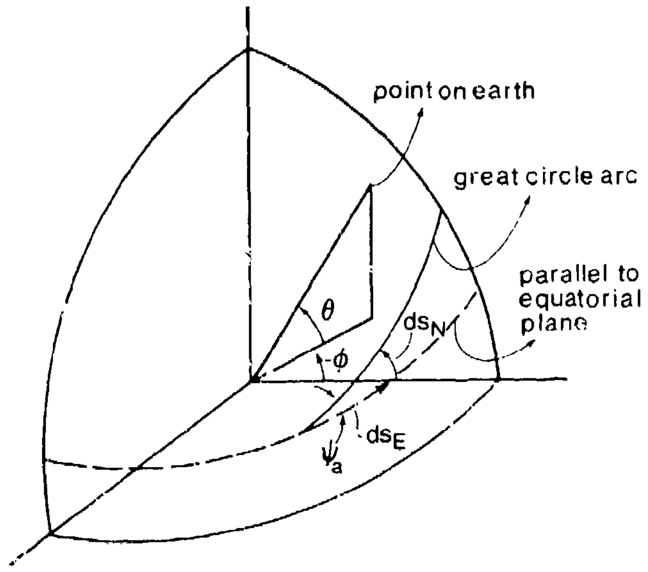

Figure C2. Latitude and Longitude Angles, Where ϕ = 0 Passes Through the Greenwich Time Base

is fixed in this case and θ (ϕ) is indeterminate. Except for this special case, A and B are determined for the particular great circle passing through these two points by using the angular surface locations of the subsolar (θ_s, ϕ_s) and observer (θ_o, ϕ_o) points to obtain

$$A = \frac{\tan\theta_s \sin\phi_o - \tan\theta_o \sin\phi_s}{\cos\phi_s \sin\phi_o - \cos\phi_o \sin\phi_s} \tag{C2}$$

and

$$B = \frac{\tan\theta_o \cos\phi_s - \tan\theta_s \cos\phi_o}{\cos\phi_s \sin\phi_o - \cos\phi_o \sin\phi_s} \; . \tag{C3}$$

The absolute azimuth angle $\psi_{a,os}$ for the plane containing the great circle segment OS can be written as

$$\tan \psi_{a,os} = \frac{ds_N}{ds_E} = \frac{-1}{\cos\theta} \frac{d\theta}{d\phi} \; , \tag{C4}$$

where $d\theta/d\phi$ along this path is given by

$$\frac{d\theta}{d\phi} = \frac{B\cos\phi - A\sin\phi}{[1 + \tan^2\theta]} \quad . \tag{C5}$$

The relations given in Eq. (C4) can be derived from considerations based on Figure C2. Using the observer point location, the equations above are combined to obtain

$$\tan\psi_{a,os} = \frac{A\sin\phi_o - B\cos\phi_o}{[1 + \tan^2\theta_o]\cos\theta_o}$$

$$= \frac{\tan\theta_o\cos[\phi_s - \phi_o] - \tan\theta_s}{[1 + \tan^2\theta_o]\cos\theta_o\sin[\phi_s - \phi_o]} \quad . \tag{C6}$$

The relative azimuth between the line-of-sight OP plane and the OS plane is then given by

$$\psi_{r,o} = \psi_{a,os} - \psi_{a,op} \quad . \tag{C7}$$

It is then necessary to calculate the angle Δ_o subtended at the earth center by radial lines from the sun and the observer. Using the dot product between position vectors on the unit sphere, it can be shown that

$$\cos\Delta_o = \cos\theta_s\cos\phi_s\cos\theta_o\cos\phi_o +$$

$$\cos\theta_s\sin\phi_s\cos\theta_o\sin\phi_o +$$

$$\sin\theta_s\sin\theta_o$$

$$= \cos\theta_s\cos\theta_o\cos[\phi_s - \phi_o] + \sin\theta_s\sin\theta_o \quad . \tag{C8}$$

The two angles $\psi_{r,o}$ and Δ_o, together with the multi-path altitude and zenith information, specify the three-dimensional single scattering geometry completely for any scattering source point. However, the angle $\psi_{r,p}$ between the PS and OP planes is yet to be obtained.

It proves convenient to make a coordinate transformation so that the line-of-sight optical path is more easily parameterized. In the original configuration, the longitude and latitude of each scattering point are not known and cumbersome to calculate. The transformation used moves the subsolar point and observer location on the sphere so that the line-of-sight runs east from an observer on the equator at ($\theta'_o = 0$, $\phi'_o = 0$). The angles ψ_o (short notation for $\psi_{r,o}$) and Δ_o are left invariant by the transformation so that the relative position of the sun in the sky is the same for the observer. No physical changes or approximations are introduced through this transformation. As one can see from Figure C3, by using Eq. (C5) and Eq. (C8) for the new coordinates, this transformation must satisfy the following equations for θ'_s and Δ_o:

$$\tan \theta'_s = \tan \psi_o \sin \phi'_s \tag{C9}$$

and

$$\cos \Delta_o = \cos \theta'_s \cos \phi'_s \quad . \tag{C10}$$

These conditions, when inverted, define the latitude θ'_s and longitude ϕ'_s of the new subsolar point in terms of the fixed angles ψ_o and Δ_o, that is,

$$\tan \phi'_s = - \tan \Delta_o \cos \psi_o \tag{C11}$$

and

$$\sin \theta'_s = \sin \Delta_o \sin \psi_o \quad . \tag{C12}$$

A line-of-sight scattering point P now has the new latitude and longitude coordinates ($\theta'_p = 0$, $\phi'_p = -\beta$), where β is the angle subtended at earth center by radial lines to P and the observer O.

It is now possible to compute the relative azimuth angle between two path legs, that is, between the vertical plane containing PS and the vertical plane containing OP. The azimuth angle at $(0, -\beta)$ for the primary solar path connecting $(0, -\beta)$ and (θ'_s, ϕ'_s) is given by

$$\tan [\psi_p (\beta)] = \frac{\sin\Delta_o \sin\psi_o}{\cos\beta \sin\Delta_o \cos\psi_o - \sin\beta \cos\Delta_o} \quad . \tag{C13}$$

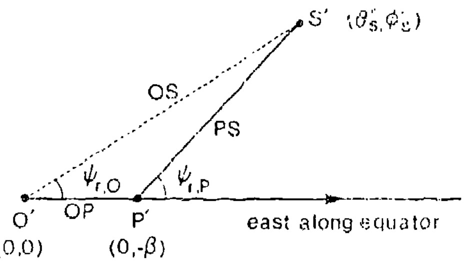

Figure C3. Looking Down on the Transformed Scattering Geometry. The line-of-sight lies on the equator. The subsolar point at (θ_s', ϕ_s') has the same relative position as in Figure C1

It is also necessary to calculate the angle $\Delta(\beta)$ subtended at the earth center by radial lines to the sun and the scattering point $(0, -\beta)$. This is given by

$$\cos[\Delta(\beta)] = \cos\Delta_o \cos\beta - \sin\beta \sin\Delta_o \cos\psi_o \quad , \tag{C14}$$

where in the absence of refractive bending $\Delta(\beta)$ would be the zenith angle of the sun as viewed from the scattering point. In the presence of refraction $\Delta(\beta)$ can be used as an initial guess for the actual zenith angle, and the primary solar path can be tracked iteratively to correct for refraction and obtain the correct zenith angle. The scattering point altitude $H1'(\beta)$ and approximate zenith angle $\Delta(\beta)$ are used to specify the starting point of the primary solar path leg from P to space.

The set of angles that are discussed above is sufficient to track both legs of each L-shaped single scattering path. One additional angle, the included angle for single scattering $\gamma(\beta)$, is needed for the phase function in the scattering source term. That angle is given by

$$\cos\gamma = \hat{n}_{ps} \cdot \hat{n}_{op} \quad , \tag{C15}$$

where each path direction vector refers to the local direction at the scattering point. In terms of the two local zenith angles α_{ps} and α_{op} at the scattering point and the relative azimuth between vertical planes $\psi_p(\beta)$, the included angle becomes

$$\cos[\gamma(\beta)] = \sin\alpha_{ps} \sin\alpha_{op} \cos[\psi_p(\beta)] + \cos\alpha_{ps} \cos\alpha_{op} \quad . \tag{C16}$$

The scattering angle γ and the cumulative absorber and scattering amounts are computed for each scattering point which contributes to the intensity in the sum given by Eq. (33). LOWTRAN specifically uses as scattering source points the intersections of the line-of-sight with the model atmospheric layer boundaries.

Appendix D

Development of the Standard LOWTRAN Phase Functions

In developing the set of standard aerosol phase functions stored in LOWTRAN, the need for reasonable accuracy was balanced against the desire to keep the memory requirements compatible with the other parts of the LOWTRAN code. The phase functions for each of the LOWTRAN aerosol models were calculated at 27 different wavelengths between 0.2 and 40 μm. These frequencies were chosen so that all the significant features in the refractive indices of the aerosol particles were included and the phase functions for other wavelengths could be found by interpolation.

The phase functions were calculated using Mie scattering theory for spherical particles. While the assumption of sphericity is valid for the liquid aerosols, it is not for the dry and dustlike particles. However, there is no practical method for exact calculation of scattering by nonspherical particles and replacing irregularly shaped particles by equivalent spheres, generally gives reasonable (although not completely correct) results. The errors introduced by this approximation are less than the other uncertainties in the properties of the aerosol models and the other approximations made in the subsequent use of the phase functions.

While the phase functions were determined for all the models at 27 wavelengths it was recognized that to store such a large data set would add significantly to the length of LOWTRAN. This data set consisted of 702 phase functions or 23,868 data points (26 models × 27 wavelengths × 34 angles), which exceeds

the combined length of all data subroutines currently in LOWTRAN 6. This full set of phase functions is provided as a separate data file on the LOWTRAN tape obtained from the National Climatic Center, and they are tabulated by Shettle et al.[1] A reduced set of 70 phase functions was chosen, each of which could be used to approximate a number of phase functions from the full set. A look-up table is used with a cross-reference from each of the 702 pairs of 26 aerosol models and 27 wavelengths to one of the 70 standard phase functions.

This reduced set of phase functions was chosen by the following several step process. The rms difference (δ_{ij}) and the correlation (r_{ij}) between all pairs of phase functions were calculated:

$$\delta_{ij} = \frac{1}{34} \sum_{k=1}^{34} \{\ln [P_i(\theta_k)] - \ln [P_j(\theta_k)]\}^2 \quad , \quad i, j = 1, 2, ..702 \tag{D1}$$

$$r_{ij} = \frac{\sum\limits_k w_k \cdot \sum\limits_k w_k P_i(\theta_k) P_j(\theta_k) - \sum\limits_k w_k P_i(\theta_k) \sum\limits_k w_k P_j(\theta_k)}{\sigma_i \cdot \sigma_j} , \tag{D2}$$

where

$$w_k = \frac{4}{[P_i(\theta_k) + P_j(\theta_k)]^2}$$

$$\sigma_i = \left\{ \sum_k w_k P_i^2(\theta_k) \cdot \sum_k w_k - \left[\sum_k w_k P_i(\theta_k) \right]^2 \right\}^{1/2}$$

$$\sigma_j = \left\{ \sum_k w_k P_j^2(\theta_k) \cdot \sum_k w_k - \left[\sum_k w_k P_j(\theta_k) \right]^2 \right\}^{1/2} .$$

The logarithm in Eq. (D1) and the weighting factor, w_k, in Eq. (D2) were both used to reduce the effect of a few extreme values, since in some cases the values of the phase function versus angle range over 5 or 6 orders of magnitude. The value of δ_{ij} can be shown to be approximately equal to the average relative difference between $P_i(\theta)$ and $P_j(\theta)$.

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1. Shettle, E.P., Abreu, L.W., and Moose, R. (1983) Angular Scattering Properties of the Atmospheric Aerosols, AFGL-TR-83- (to be published).

These two measures of the difference between the phase functions were used to group them into 70 subsets of similar scattering functions. Where possible, a criteria of $\delta_{ij} \leq 0.20$ and $r_{ij} \geq 0.980$ was used for all i and j in a subset. In some cases it was necessary to relax this criteria to $\delta_{ij} \leq 0.40$ and $r_{ij} \geq 0.900$. For a few of the scattering functions it was not possible to find any other phase functions that were similar even with the weaker criteria. These were left as individual phase functions.

The mean value of all the scattering functions within each of the 70 subsets were calculated at each of the scattering angles. The original 702 phase functions were then compared with these 70 resulting "mean" phase functions to determine the closest match using Eqs. (D1) and (D2). This resulted in some changes in the composition of some of the subsets. The mean scattering function was then calculated for each of these 70 modified subsets of scattering functions. These final phase functions were used as the set of standard LOWTRAN phase functions. These standard LOWTRAN scattering functions are shown in Figures D1 through D10.

With this final set, 50 percent of the original 702 phase functions matched one of the standard phase functions within a criteria of $\delta_{ij} \leq 0.10$ and $r_{ij} \geq 0.995$, and 95 percent met a criteria of $\delta_{ij} \leq 0.20$ and $r_{ij} \geq 0.975$. The poorest agreement between the original phase functions and the corresponding member of the

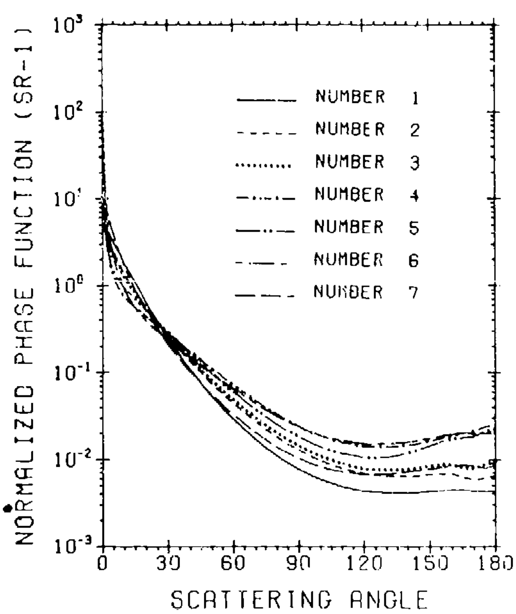

Figure D1. Standard LOWTRAN Phase Functions Numbers 1 to 7

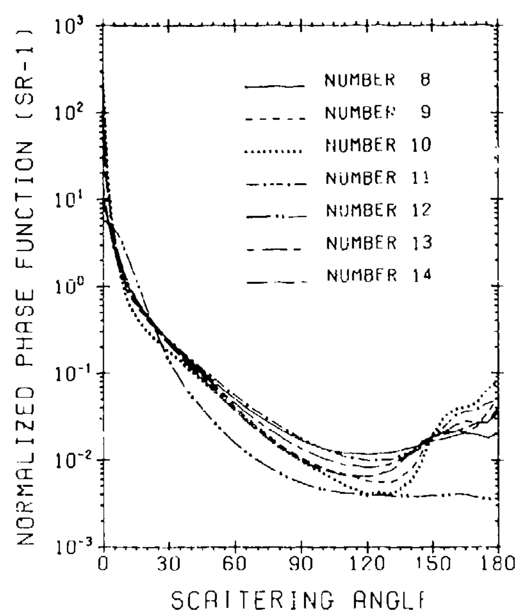

Figure D2. Standard LOWTRAN Phase Functions Numbers 8 to 14

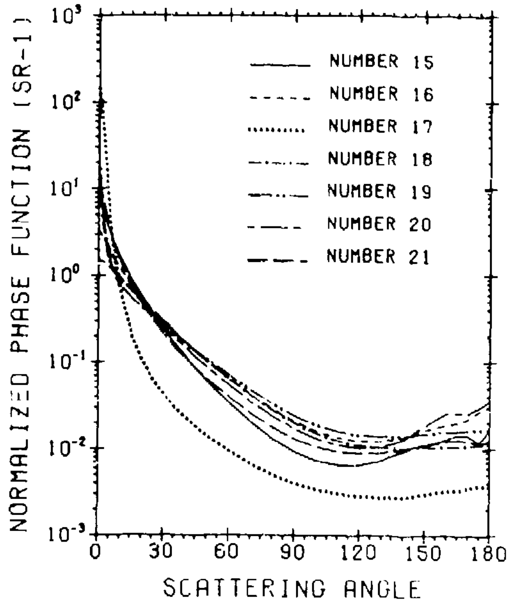

Figure D3. Standard LOWTRAN Phase Functions Numbers 15 to 21

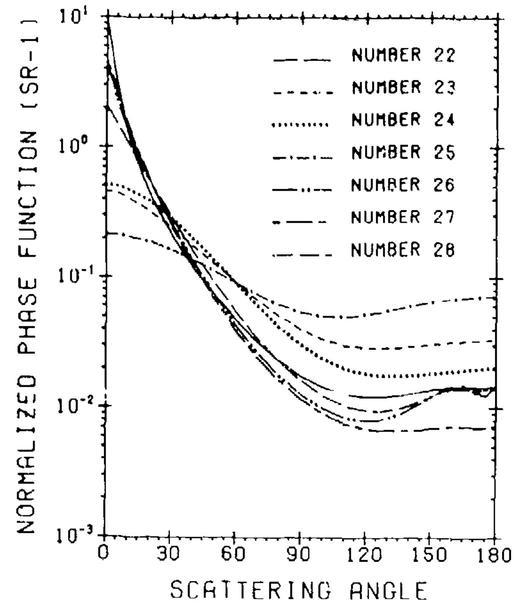

Figure D4. Standard LOWTRAN Phase Functions Numbers 22 to 28

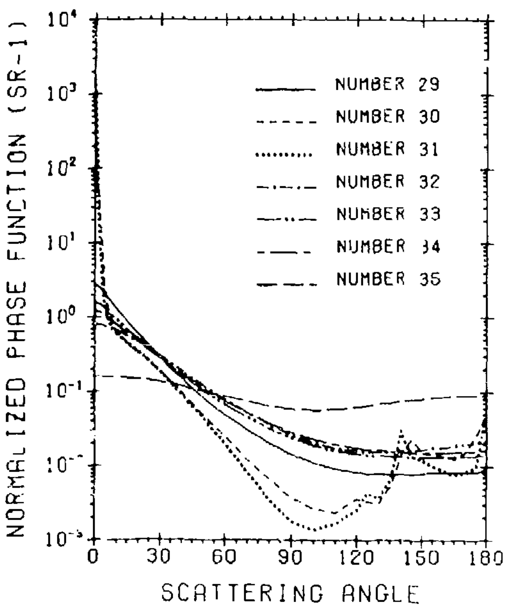

Figure D5. Standard LOWTRAN Phase Functions Numbers 29 to 35

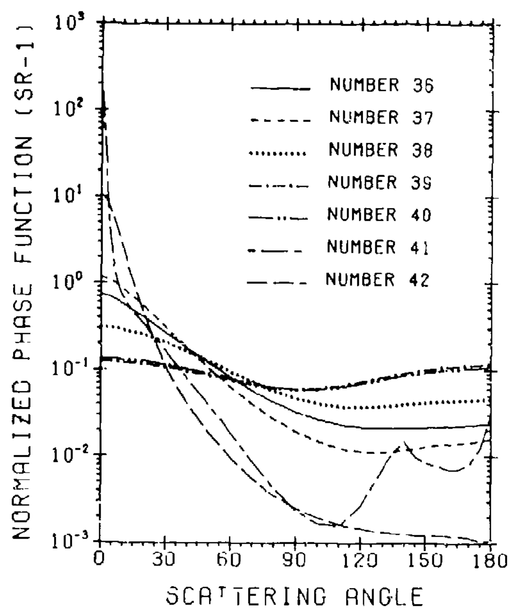

Figure D6. Standard LOWTRAN Phase Functions Numbers 36 to 42

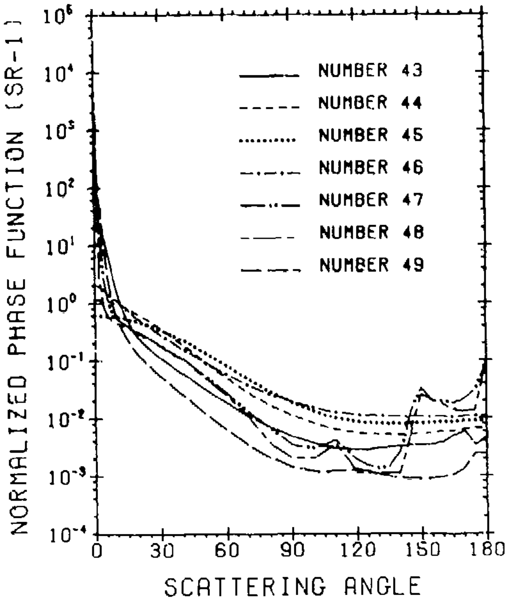

Figure D7. Standard LOWTRAN Phase Functions Numbers 43 to 49

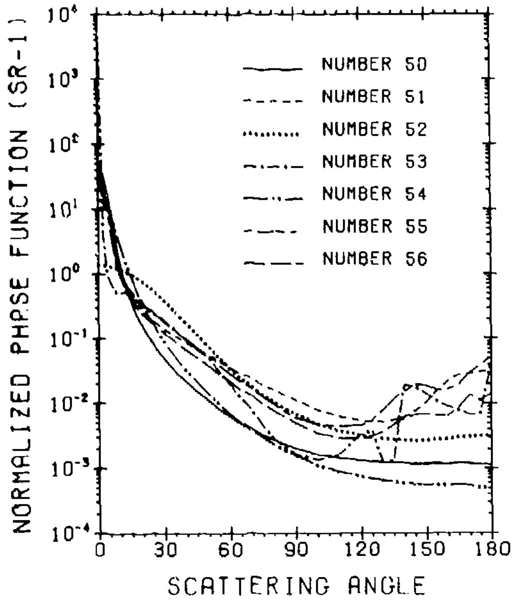

Figure D8. Standard LOWTRAN Phase Functions Numbers 50 to 56

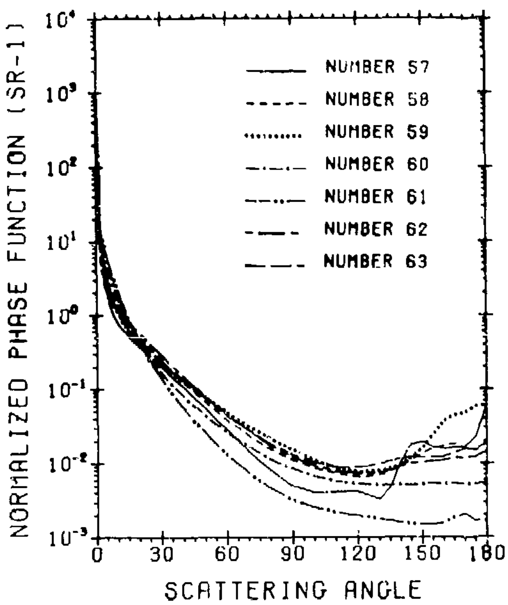

Figure D9. Standard LOWTRAN Phase Functions Numbers 57 to 63

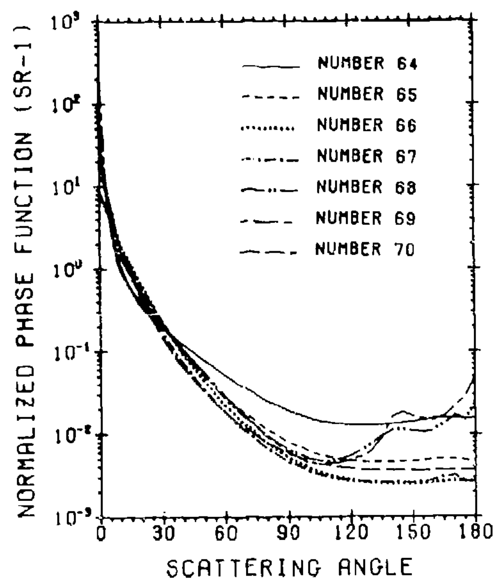

Figure D10. Standard LOWTRAN Phase Functions Numbers 64 to 70

Table D1. Cross Reference Table. Standard LOWTRAN phase functions for each aerosol model and wavelength

(a) Wavelength range 0.2 to 6.0 μm

MODEL NO.	MODEL NAME	0.20	0.30	0.55	0.69	1.06	1.54	2.00	2.50	2.70	3.00	3.20	3.39	5.00	6.00
1	RURAL RH00	3	5	4	4	4	6	8	22	21	22	26	26	26	27
2	RURAL RH70	3	5	4	4	4	6	8	22	21	21	22	26	26	27
3	RURAL RH80	3	5	5	5	19	6	8	21	7	21	22	8	26	1
4	RURAL RH99	58	58	62	62	62	63	63	63	60	64	64	64	21	70
5	MARIT RH00	59	11	11	11	20	20	20	28	28	16	16	16	16	37
6	MARIT RH70	9	59	11	13	13	26	26	26	27	29	46	28	28	29
7	MARIT RH80	9	9	14	14	14	15	15	15	66	65	27	26	29	27
8	MARIT RH99	57	57	69	69	69	68	68	68	61	70	60	21	7	66
9	URBAN RH00	2	18	18	19	19	6	22	22	22	22	22	22	29	29
10	URBAN RH70	2	3	18	18	19	6	22	22	21	22	22	22	27	27
11	URBAN RH80	2	3	18	18	19	6	22	21	7	22	22	22	27	27
12	URBAN RH99	58	58	62	62	62	62	63	63	60	64	64	64	21	60
13	OCEAN RH00	10	59	11	11	13	20	20	28	28	16	16	16	16	37
14	OCEAN RH70	10	10	14	14	13	13	26	26	27	29	29	28	28	29
15	OCEAN RH80	10	69	14	14	14	15	15	7	66	65	27	26	29	1
16	OCEAN RH99	47	57	69	69	69	68	68	68	61	70	60	21	7	66
17	TROPO RH00	29	16	32	32	36	36	23	23	23	38	38	38	25	25
18	TROPO RH70	29	16	32	32	32	36	23	23	23	38	38	38	38	25
19	TROPO RH80	29	28	37	37	32	36	36	23	23	23	23	23	38	25
20	TROPO RH99	15	26	28	28	37	37	32	32	32	23	23	23	23	38
21	STRT H2SO4	20	20	37	37	24	23	38	25	25	35	35	35	40	40
22	AGED VOLC	7	20	16	37	32	32	24	23	23	23	38	38	25	25
23	FRESH VOLC	17	51	13	13	20	20	28	28	37	37	37	37	32	32
24	RAD FOG	47	30	55	55	55	13	15	12	42	12	1	26	44	52
25	ADVEC FOG	48	53	31	31	31	41	41	41	49	17	17	17	56	50
26	MET DUST	59	59	11	11	20	20	28	28	46	46	46	46	33	33

Table D1. Cross Reference Table. Standard LOWTRAN phase functions for each aerosol model and wavelength (Contd)

(b) Wavelength range 7.2 to 40.0 μm

MODEL NO.	MODEL NAME	7.2	7 .	8.7	9.2	10.0	10.6	12.5	15.0	17.2	18.5	21.3	30.0	40.0
1	RURAL RH00	29	1	34	34	34	34	33	33	36	36	36	36	23
2	RURAL RH70	29	1	34	33	33	33	46	46	34	34	36	36	23
3	RURAL RH80	27	1	46	46	46	29	29	46	34	34	34	36	23
4	RURAL RH99	65	65	65	65	66	66	65	27	29	29	46	33	34
5	MARIT RH00	37	37	32	36	32	32	32	36	23	23	23	38	25
6	MARIT RH70	28	28	37	37	37	37	34	36	36	36	23	23	38
7	MARIT RH80	29	29	29	29	29	29	46	34	36	36	36	23	23
8	MARIT RH99	1	1	1	1	66	66	1	29	46	46	33	34	36
9	URBAN RH00	46	29	34	34	34	34	34	34	36	36	36	23	23
10	URBAN RH70	29	27	33	33	46	46	46	33	34	34	36	36	23
11	URBAN RH80	27	27	46	29	29	29	29	46	33	34	34	36	36
12	URBAN RH99	7	65	65	65	66	67	65	7	27	27	29	46	33
13	OCEAN RH00	37	37	32	36	32	32	32	36	23	23	23	38	25
14	OCEAN RH70	28	28	37	37	37	37	33	32	36	36	23	23	38
15	OCEAN RH80	29	29	29	29	29	29	46	34	36	36	36	23	23
16	OCEAN RH99	1	1	1	1	66	66	1	29	46	46	33	34	36
17	TROPO RH00	25	25	25	25	25	25	35	35	35	35	35	40	39
18	TROPO RH70	25	25	25	25	25	25	35	35	35	35	35	40	39
19	TROPO RH80	25	25	25	25	25	25	35	35	35	35	35	40	40
20	TROPO RH99	38	38	38	25	25	25	25	35	35	35	35	35	40
21	STRT H2SO4	39	39	39	39	39	39	39	39	39	39	39	39	39
22	AGED VOLC	35	35	35	25	35	35	40	40	40	40	40	39	39
23	FRESH VOLC	24	24	23	23	38	38	38	38	38	38	38	25	35
24	RAD FOG	44	44	45	45	45	45	24	23	38	38	38	25	35
25	ADVEC FOG	43	43	67	61	42	54	42	12	12	12	12	1	44
26	MET DUST	34	34	34	34	36	36	36	36	23	23	23	38	38

standard scattering functions was $\delta_{ij} = 0.29$ and $r_{ij} = 0.940$. A comparison of the original phase function and the standard function used for this case is shown in Figure D11.

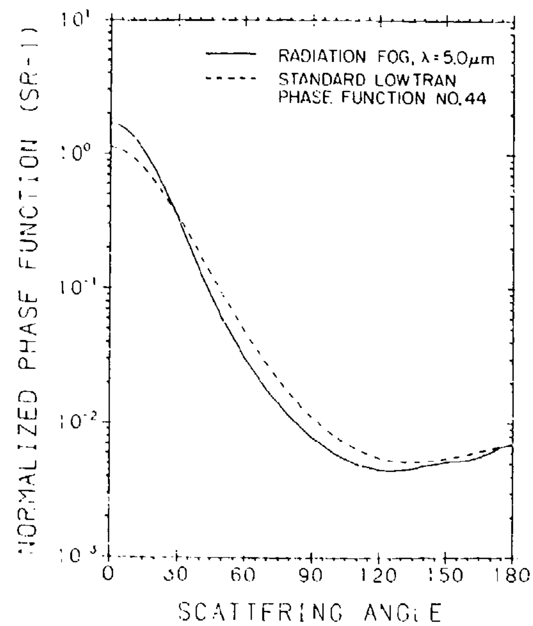

Figure D11. Comparison of One of the Original Aerosol Model Phase Functions With the Corresponding Standard LOWTRAN Phase Function (see Table D1), Showing the Poorest Agreement

A look-up table is stored in LOWTRAN, identifying for each of the original phase functions (26 models × 27 wavelengths), which standard phase functions should be used (see Table D1). For wavelengths and/or relative humidities other than used in the original set of Mie calculations, LOWTRAN will interpolate between the appropriate standard phase functions as indicated by the table.